AN EXPERIMENTAL INVESTIGATION FOR DETERMINING SUSCEPTIBILITY LIMITS AND TECHNIQUES FOR DESENSITIZATION OF SOLID STATE ELECTRONIC EQUIPMENT TO POWER LINE TRANSIENTS

NAVAL CIVIL ENGINEERING LABORATORY

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By

M. N. Smith

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Port Hueneme, California 93043

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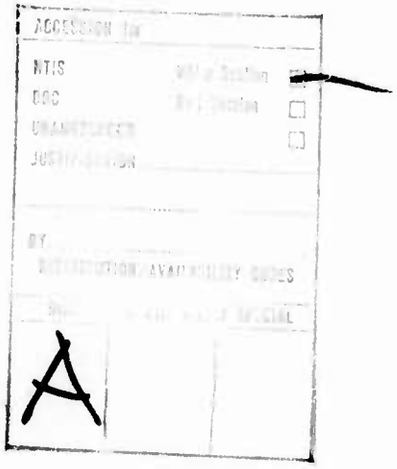

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Government and commercial facilities are becoming more operationally dependent on sensitive and complex electronics systems. These systems require precise and continuous supply of electric power for trouble-free operation. Desensitization of sensitive electronic equipment to power supply abnormalities is one approach toward achieving increased operational reliability. This report covers the results of an experimental investigation to determine the susceptibility limits of a selected solid state electronic test unit and to evaluate techniques for desensitizing the unit to a variety of typical power line transients. It was concluded that when sensitive electronic systems are being developed, susceptibility tests should be performed to provide design criteria for desensitizing the equipment on a cost effective basis.

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INTRODUCTION

Government, as well as commercial facilities, are becoming partially, and in some cases, totally dependent on sensitive and complex operational systems. These operational systems require precise and reliable electric power for trouble-free operation. Unfortunately, this ever-increasing demand for quality power is rising at a rate faster than utility companies can increase power generation and upgrade distribution facilities. As a result, more and more users of sensitive equipment are required to provide buffering and conditioning equipment, or, in the worst case, specialized and costly power sources such as Uninterruptible Power Systems. Conditioning utility power is not only costly, but in some cases, does not result in a significant increase in operational reliability over that available by direct use of utility power.

The desensitization of sensitive equipment to power supply abnormalities is another approach which appears to have considerable merit, but very little effort is being expended toward desensitizing such equipment. An experimental investigation was conducted on a solid state electronic counter as a test unit to determine the transient susceptibility limits of the unit and to evaluate techniques for desensitizing the unit to a variety of transients. The electronic counter was selected as the test unit because most electronic circuits used throughout the instrument are commonly used in most sensitive electronic equipment.

TEST PROCEDURE

The power supply output of the test unit consists of five (5) voltage levels: +170 VDC unregulated, -130 VDC unregulated, +20 VDC regulated, -15 VDC regulated, and +13 VDC regulated. Each of these voltage outputs, the main gate signal and the input AC power were simultaneously monitored and recorded on a light beam oscillograph.

The test unit was subjected to power parameter variations outlined in Appendix A, and was operational with the function control in the frequency position, the time base set to 1 second position, the signal input level set to 0.1 volt and the input signal coupled through the AC input connector. The unit was operated in a manner where under normal conditions, the correct readout on the digital counters sould be 10,000.000 Khz. Failure of the test unit was recorded when the gate signal dropped to a low state (zero volts) or an erroneous count was observed on the digital counters. Figure 1 is a block diagram of connections and instrumentation arrangement for the test.

SUSCEPTIBILITY TEST RESULTS

Steady-State Overvoltages

For this test, the input AC voltage was increased by increments of 5 volts from the base of 115 RMS volts to 140 V. Voltages of 130 volts and higher were always applied for a period of one minute or less so damage to the test unit would not occur due to overheating. Operational failure or physical damage did not occur during the steady-state overvoltage test. Figure 2 shows the input AC, +170 VDC, -130 VDC, +20 VDC, -15 VDC and +13 VDC. As shown, the two unregulator voltages increased with each increase of the input AC power, but the three regulated voltages remained at a constant level throughout the steady-state overvoltage test.

Steady-State Undervoltages

Starting at 115 VRMS, the input power to the test unit was decreased by increments of 5 volts for this test until the instrument failed operationally. The test unit operated normally down to 90 VRMS but failed operationally at 85 VRMS The actual failing voltage is 87 VRMS. Figure 3 shows the input AC power, +170 VDC, -130 VDC, +20 VDC, -15 VDC and +13 VDC at each 5 volt increment from 115 to 85 VRMS. As shown down to 95 VRMS, the unregulated +170 and -130 VDC lowered in value, but the three regulated voltages remained at a constant value. At 90 VRMS, the two unregulated voltages dropped lower in value, the +20 and +13 VDC dropped slightly and developed some ripple, but the -15 VDC remained constant. At 85 VRMS, all five (5) power supply voltages dropped in value with all three regulated voltages developing ripple. The test unit would not function under these conditions.

Momentary Power Outage

Outages on the input AC power greater than 1/8 cycle caused the test unit to fail. The test unit operated normally during outages of less than 1/8 cycle. With power outages of 1/8 cycle, the test instrument failed approximately 50% of the time. The test instrument failed consistently with power outages of 1/4 cycle or greater. Figures 4, 5, and 6 show power outages of approximately 1/8, 1/4, and 1/2 cycles, respectively, with no failure for the 1/8 cycle, but a failure for both 1/4 and 1/2 cycle outages.

Momentary Undervoltage

Momentary undervoltages in 5 volt increments down to 75 volts from the base 115 volts for durations of 1/2 to 20 cycles, were applied

to the test unit. The test unit operated normally when undervoltages down to 100 volts were applied for duration up to 20 cycles. However, it failed approximately 1/3 of the time when momentary undervoltages of 95 volts were applied for 1 1/2 cycles.

The test unit failed when undervoltages of 90 or 85 volts were applied for 1 cycle and when undervoltages of 75 were applied for 1/2 cycle. Figure 7 shows that the test unit operated normally when a 1 cycle, 95 volt undervoltage was applied. Figure 8 shows that the test unit failed to operate when a 1 1/2 cycle, 95 volt undervoltage was applied. Similarly, Figure 9 shows that the unit failed to operate after a 1/2 cycle, 75 VRMS undervoltage was applied.

Momentary Overvoltage

Momentary overvoltages in 5 volt increments for durations of 1/2 to 20 cycles above the base 115 volts to 160 volts were applied to the test unit. Figure 10 shows a 1/2 cycle, 145 volt overvoltage causing no failure of the test unit, and Figure 11 shows a 20 cycle, 160 volt overvoltage also causing no failure of the test unit.

Negative Polarity Pulse Transients

Negative polarity pulse transients with magnitudes from 50 to 600 volts peak, and durations of approximately 2 to 2,000 microseconds were applied at phase angles from 0 through 360°. Figure 12A shows a negative polarity pulse applied at approximately 270°, 2,000 microseconds wide and 350 volts peak-to-peak. This pulse did not cause the test unit to fail, but the pulse shown in Figure 12B, which is approximately the same amplitude but only 5 microseconds in duration, did cause the test unit to fail. Figures 12C and 12D show negative pulse applied at a 90° phase angle with neither pulse causing the test unit to fail. The negative pulses that caused the unit to fail had durations of less than 10 microseconds and amplitudes greater than 200 volts peak. Negative pulses applied from 0 through 180 degrees require a greater magnitude than negative pulses applied between 180 and 360 degrees to cause the test unit to fail.

Positive Polarity Pulse Transients

Positive polarity pulse transients with magnitudes of 50 to 600 volts peak and durations from 2 to 1000 microseconds were applied at phase angles from 0 through 360°. Figures 13A and 13B show positive pulses applied at a phase angle of approximately 90° with amplitudes greater than 200 volts peak and durations of approximately 600 and 5 microseconds, respectively. The 5 microsecond pulse caused the test unit to fail while the 600 microsecond pulse did not cause a failure. Figures 13C and 13D show positive polarity pulses applied to approximately 270° with amplitudes greater than 200 volts peak and durations of approximately 400 and 5 microseconds respectively. Neither pulse caused the unit to fail. Only positive polarity pulses with amplitudes greater than 200 volts peak and durations less than 10 microseconds caused the unit to fail. Positive pulses applied from 180 through 360 degrees require a greater magnitude than positive pulses applied between 0 and 180 degrees to cause the test unit to fail.

Momentary Increase and Decrease in Frequency at Various Rate of Change

The input power frequency to the test unit was varied up to 66 and down to 54 hz in steps of .2, .5, 1, 1.5, 2, 4, and 6 hz at a rate of change of 1 through 10 hz. No failures occurred during any of these frequency changes.

Superimposed High Frequency Voltages

High frequency voltage waveforms from 300 hz to 10 Khz were superimposed on the input AC power with magnitudes of 50 volts RMS and for durations of 1/2 to 20 cycles of the 60 hz frequency. Figures 14a and 14b show 300 hz for durations of 1/2 and 5 cycles. Figures 14c and 14d show 10 Khz for durations of 1/2 and 5 cycles. None of the superimposed high frequencies caused physical damage or operational failure of the test unit.

Square Wave Input Power

The test unit was supplied with 60 hz square wave input power for a period of two hours with no physical damage or operational failure. Figure 15 shows the voltage waveshape of this 60 hz square wave power.

TEST UNIT DESENSITIZATION

The power supply in the test unit provides five (5) output voltage levels, namely +170 and -130 VDC unregulated; -15 and +13 and +20 VDC regulated. The minus 15 volt supply consists of a full-wave bridge rectifier whose output is filtered by an LC network then regulated by a transistorized series regulator. The plus 13 volt supply consists of a full-wave bridge rectifier whose output is filtered by an LC network then regulated by a transistorized series regulator. The +20 volt supply is provided by a full-wave bridge rectifier, the output of which is smoothed by a capacitor then regulated by a transistorized series regulator that is referenced directly to the +13 volts supply. The +170 volt supply consists of a conventional full-wave rectifier, a capacitor to reduce the ripple and is referenced to the +20 volts. Part of the output of the -130 volt supply is connected to a shunt regulator (zener diode) which provides -56 volts to the -15 volt regulator. Figure 21 is a simplified diagram of the test unit power supply.

The power supply provides stable output of the regulated levels over a range greater than specified by the manufacturer (103-127 VRMS) provided input line power is continuous and does not contain momentary fluctuations. With this design, little or no reserve power is available to provide a continuous output when the input voltage momentarily drops or is lost. Consequently, the test unit fails under these conditions. There are numerous methods that can be employed to improve the output of this power supply under these conditions. Some methods are very costly and others require little or no change in cost or design.

DESENSITIZATION TO MOMENTARY POWER OUTAGES AND VOLTAGE DIPS

The simplest method for desensitizing the test unit to momentary outages and voltage dips is to increase the capacitance value of the capacitors in the power supply filters. Shown in Figure 21 are the 5 filter capacitors and their capacitance values, which range from 20 to 1,500 microfarads. All five filter capacitors were replaced with capacitors of increased capacitance that would physically fit the configuration of the test unit without a wiring change. C1, C4 and C5's value was increased to 2,500 microfarad and C2 and C3 was increased to 95 microfarads. This resulted in an increase tolerance of the test unit to a power outage of 2 cycles and a voltage dip to 73 VRMS for 2 1/2 cycles versus a 1/4 cycle power outage and a 95 VRMS 1 1/2 cycle voltage dip. Figure 22a shows a 95 VRMS 1 1/2 cycle voltage dip causing the test instrument to fail. With the capacitance values increased, Figure 22b shows a 73 VRMS 2 1/2 cycle voltage dip without failure. Figure 22c shows an approximate 95 VRMS, 40 cycle voltage dip without failure. Figure 23a shows a 1/4 cycle power outage without increasing the capacitance values, without failure. Figure 23b with the capacitance values increased show a 2 1/2 cycle power outage without failure. The total cost increase by the use of capacitors with increased capacitance versus the original capacitors is $1.82. Greater tolerance to utility power anomolies by the test unit can be attained by further increasing the capacitance of the filter capacitors. This would increase the cost and require a reconfiguration of the overall packaging of the test unit. The capacitance value of the filter capacitors was further increased by the addition of external capacitors; C1 and C4 were increased to 11,000 microfarads, C15 to 15,000 microfarads, and C2 and C3 to 1,000 microfarads. With this added capacitance, Figure 24a, b, c, and d shows power outages of approximately 2 1/2, 5, 8, and 10 cycles. The three regulated voltages show no drop for a 2 1/2 cycle outage, a slight drop for 5 cycles and considerable drop at 8 and 10 cycle outage. The test unit failed only when the 10 cycle outage occurred. Although the gate signal does not drop to zero (0) during the 10 cycle outage, the indicated count was erroneous. There is a limit to increasing the capacitance of the filter capacitors because their physical size is undesirable.

Another simple method of increasing the test unit tolerance to momentary power line voltage fluxuation is by adding capacitors to the bridge side of L3 and L4. This will change these two filter networks from an L to a Pi type. Two 2,500 microfarad capacitors were added to the test unit and connected to the points previously mentioned. Figure 25a was made before the capacitors were added showing the unit failing during a 1/4 cycle power outage. After the capacitors were added, Figures 25b and c show a 1 1/2 and 2 1/4 cycle power outage. Neither caused the unit to fail. Figure 26a shows an approximate 73 VRMS 40 cycle voltage dip before the two capacitors were added, the test unit failed. Figure 26b shows approximately the same type voltage dip after the two capacitors were added, the test unit did not fail.

A combination of adding the two capacitors and replacing filter capacitors C1 through C5 with capacitors of increased capacitance that would physically fit the configuration of the test unit and not require a change in circuit connections, further increases the test unit tolerance to a power line voltage fluctuation. With the capacitors added and filter values increased, Figure 27a shows a voltage dip to approximately 73 VRMS and 40 cycles duration. Figure 27b shows an approximate 6 cycle power outage. Neither caused the test unit to fail.

DESENSITIZATION TO PULSE VOLTAGES

No pulse voltage protection was provided in the test unit. A RFI filter is provided on the input power, shown in Figure 21, consisting of L1, L2, C6, and C7. This filter is designed to prevent high frequencies generated in the test unit from appearing back on the input power line.

As noted from results of the susceptibility tests, the test unit would fail to operate only when a short duration (10 μs or less) fast rise (1 or 2 μs) pulse voltage was applied to the input power line. These pulses cause two things to occur, either the total count on the visual indicators were in error or the gate signal would drop to a low state, stopping the sample period too soon. No attempt was made to trace these pulses to the circuit in the test unit that caused the operational failures. These pulses were traced only to the DC voltage outputs of the power supply. An attempt was made to determine why a fast rise, short duration pulse with magnitudes lower than longer duration pulses would cause the unit to fail. The pulse was traced from the line side of the RFI filter, directly across the primary windings of T-1, directly across each of the four (4) secondary windings of T-1, the output of each of the five (5) bridge rectifiers and at the input and output of each of the three regulator networks. Figure 28 shows oscilloscope traces of a pulse with an approximately 5 microsecond duration, 1 microsecond rise time, 200 volts peak amplitude superimposed on the input power line which caused the test unit to fail operationally. This pulse is traced through to the output of the -15 volt regulator. Figure 28a and b show the pulse on the power line with Figure 28b expended to 5 microseconds per centimeter horizontally and 28a and b, 170 V percentimeter vertically. Figure 28c and d show the pulse at the bridge side of L3 in the -15 volt network. Both 28c and d are 15 volts percentimeter vertically with 28c, 20 microsecond and 28d, 5 microseconds percentimeter horizontally. Figures 28 e and f are at the junction of L3 and C1. Both 28e and f are 5 volts percentimeter vertically with 28e, 2 milliseconds and 28f, 5 microsecond percentimeter horizontally. Figure 28g is on the output of the -15 volt regulator and is identical to Figure 28f. Figure 28h shows two traces, both were taken at the rectified output of the -15 volt bridge rectifier.

The sweep speed is 20 microseconds percentimeter and voltage of 15 volts percentimeter. The top trace was taken with L3 in the circuit and the bottom trace with L3 out of the circuit which demonstrates that the pulse voltage caused the filter, consisting of L3 and C1 to ring. The clipped portion of the second oscillation on the upper trace is caused by the bridge diodes clamping the voltage at ground potential. The bottom trace shows that with the choke coil (L3) removed, little ringing occurs and the test unit does not fail. Figures 29a through 29h have the same horizontal sweep speed and vertical voltages as their counterparts in Figure 28. In Figure 29, the pulse that was superimposed on the input power was approximately 255 volts in amplitude with a 30 microsecond duration. This pulse did not cause the test unit to fail. Figure 29h shows two traces with the same sweep speed and voltage as 28h and again the top with L3 in and the bottom with L3 out. Figure 28f and 29f show that a pulse with a fast rise and short duration cause a more violent ringing (oscillation) at the output of L3 and L4 than a slower rise longer duration pulse. The same sequence of events occur on the +13 volts network when the same type pulses are superimposed on the input power. The output of the +20 volt regulator with a 5 microsecond, 200 volt pulse is shown in Figure 30a and 255 volt, 30 microsecond pulse is shown in Figure 30b. The output of the +13 volt regulator with the 200 volt, 5 microsecond pulse is shown in Figure 30c and a 255 volt, 30 microsecond pulse is shown in Figure 30d.

The interwinding capacitance between the primary and secondary of transformer T-1 is very small, but this is the component that gives the electrostatic component in pulse transfer when the pulse has a very fast rising leading edge. Thus, two reasons a short duration, fast rise pulse causes the test unit to fail are (1) there is an increased transfer of energy and (2) the filter rings.

There are several methods that can be used to desensitize the test unit from harmful pulse transients on the input power. Again, as for voltage fluctuations, some methods are very costly and others require little or no change in cost or design. By knowing the types of pulse transients the unit is sensitive to, the difficulty of desensitizing the unit is greatly reduced. The simplest method for desensitizing this unit is to provide a Pi filter in the input power by adding a .01 microfarad capacitor on the load side of L1 and L2 of the existing RFI filter. This did not eliminate the pulses from entering the test unit, but it did greatly increase the unit's tolerance to these pulses. Without the added capacitors on the RFI filter, a 200 volt less than 10 microsecond duration pulse would cause the unit to fail, but with the added capacitors, it takes an approximate 575 volt, 10 microsecond duration pulse to cause failure. Another simple method was to connect a 10 microfarad capacitor across the input power line. Again, this doesn't stop the pulse from entering the test unit, but it does slow the rise of the pulse so that no failures occurred, even when pulses with amplitudes greater than 600 volts were applied on the input power.

Another simple method was to install a broadband RFI filter on the input power line. This filter, whose physical size is 3 3/4 inch long, 1 inch diameter, can be installed in the test unit with a minimum of effort. The cost for a filter of this type is approximately $15.00. With the filter installed and a pulse similar to the one shown in Figure 28a, was imposedon the input power, the unit did not fail. Figure 31 shows two oscilloscope traces, both are at the output of the -15 VDC regulator. The top trace shows the pulse as it appears on the -15 volts with the filter out of the input power line. This pulse caused the unit to fail. The bottom trace shows the same type pulse on the -15 volts with the filter in the input power line without failure of the unit. With the filter in the input power line, pulses up to 1000 volts peak were applied on the input power line without failure of the unit.

DISCUSSION

Obviously, the operation of critical equipment stops during a total power outage. More frequent, but less obvious, are these critical equipment failures caused by momentary conditions when utility power fails to remain within certain tolerances. These momentary, often undetected conditions, can result in critical equipment failures, some which are harmful. Power requirements specified by most critical equipment manufacturers are sometimes hard to achieve or maintain. Using a computer as a specific example of a critical load, and the fact that the U.S. Government is the world's largest user of computers, millions of dollars would be saved annually if computers could tolerate most utility power conditions. Unfortunately, the quality of utility power varies greatly over many graphic locations throughout the world. In a computer system complex, many adverse characteristics are generated by the computer itself. Many of the peripheral equipments in the computer system generate pulse transients and sharp changes in power demand that are felt throughout the system. Therefore, a greater effort should be attempted by designers and manufacturers of critical loads to increase the tolerance of this equipment to most utility power abnormalities.

The test unit used during these tests demonstrates that failures in critical equipment do occur when certain abnormalities occur on the utility power. Also, some of these failures can be prevented, if during the design phase, more attention is given to the actual conditions existing on utility power lines. Figures 16 through 20 are random transients recorded at various graphic locations in the USA. If any of these transients occurred on the power supplied to the test unit, it would, in all probability, have failed. The exact source of these types of transients is usually unknown. These are the transients that propagate through the power line into the critical loads. One thing is certain, the designer has difficulty protecting against something that is unknown. For this reason, when new equipment is

being developed, susceptibility tests, such as those conducted on the test unit, should be performed to provide design criteria for desensitizing the equipment on a cost effective basis. It is realized that desensitizing a single electronic unit is simple while other critical operational systems, such as a computer complex, would present a challenge to a designer. However, this added effort would be cost effective to the user.

RECOMMENDATIONS

1. Susceptibility testing of critical equipment should be a requirement in all procurement specifications.

2. Military standards and specifications should be upgraded to specify power supply parameters which are more realistic of that normally provided by utility power sources.

3. Every effort should be made to require equipment suppliers to desensitize critical electronic equipment to most utility power abnormalities.

SUMMARY OF TRANSIENT SUSCEPTIBILITY TESTS

A.	Steady State Overvoltage	140 RMS - W
B.	Steady State Undervoltage	85 VRMS - F
C.	Momentary Power Outage	1/4 Cycle - F
D.	Momentary Undervoltage	95 VRMS - 1-1/2 Cycles - F
E.	Momentary Overvoltage	160 VRMS - 20 Cycles - W
F.	Negative Polarity Pulse Transient	200 V Peak - From 180-360° - 10 Microsecond Duration - F 420 V Peak - From 0-180° - 10 Microsecond Duration - F
G.	Positive Polarity Pulse Transient	200 V Peak - From 0-180° - 10 Microsecond Duration - F 340 V Peak - From 180-360° - 10 Microsecond Duration - F
H.	Momentary Frequency Change	54 to 66 Cycles - W
I.	Superimposed High Frequency	300 hz - 10 Khz - 50 VRMS - 20 Cycles - W
J.	Squarewave Input Power	W

NOTE: W Denotes Unit Works

F Denotes Unit Failed

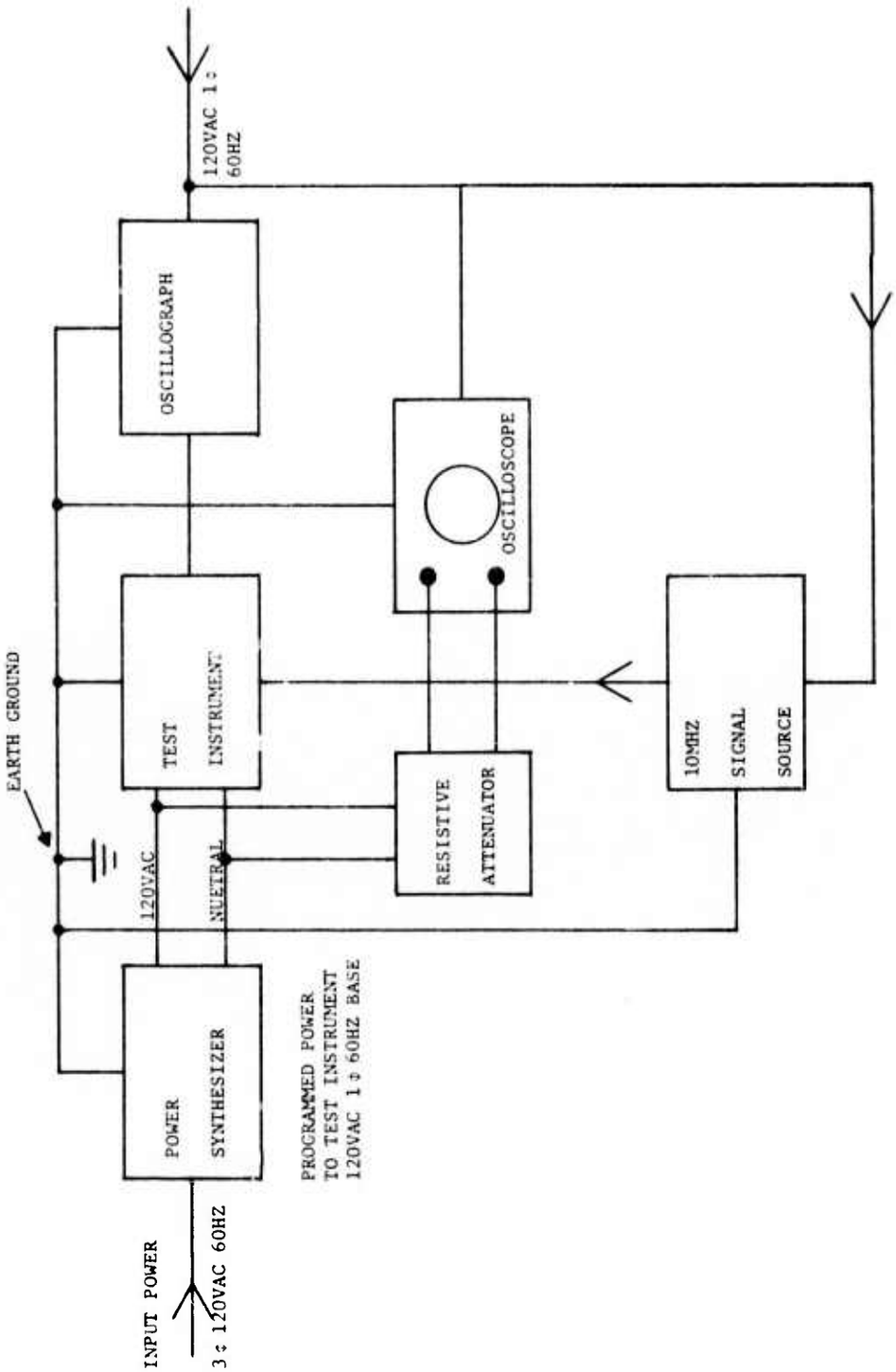


Figure 1. Test set-up block diagram

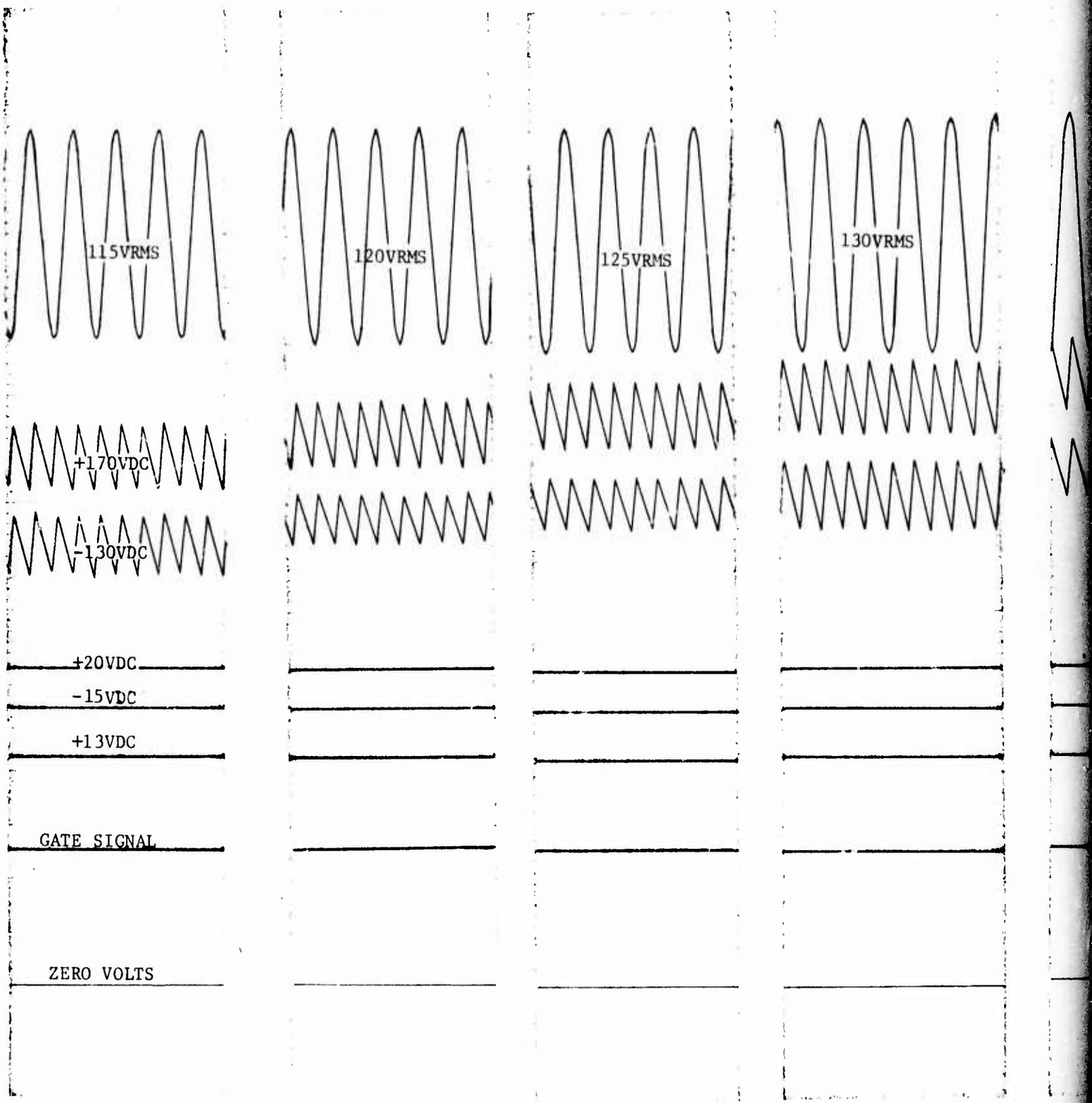
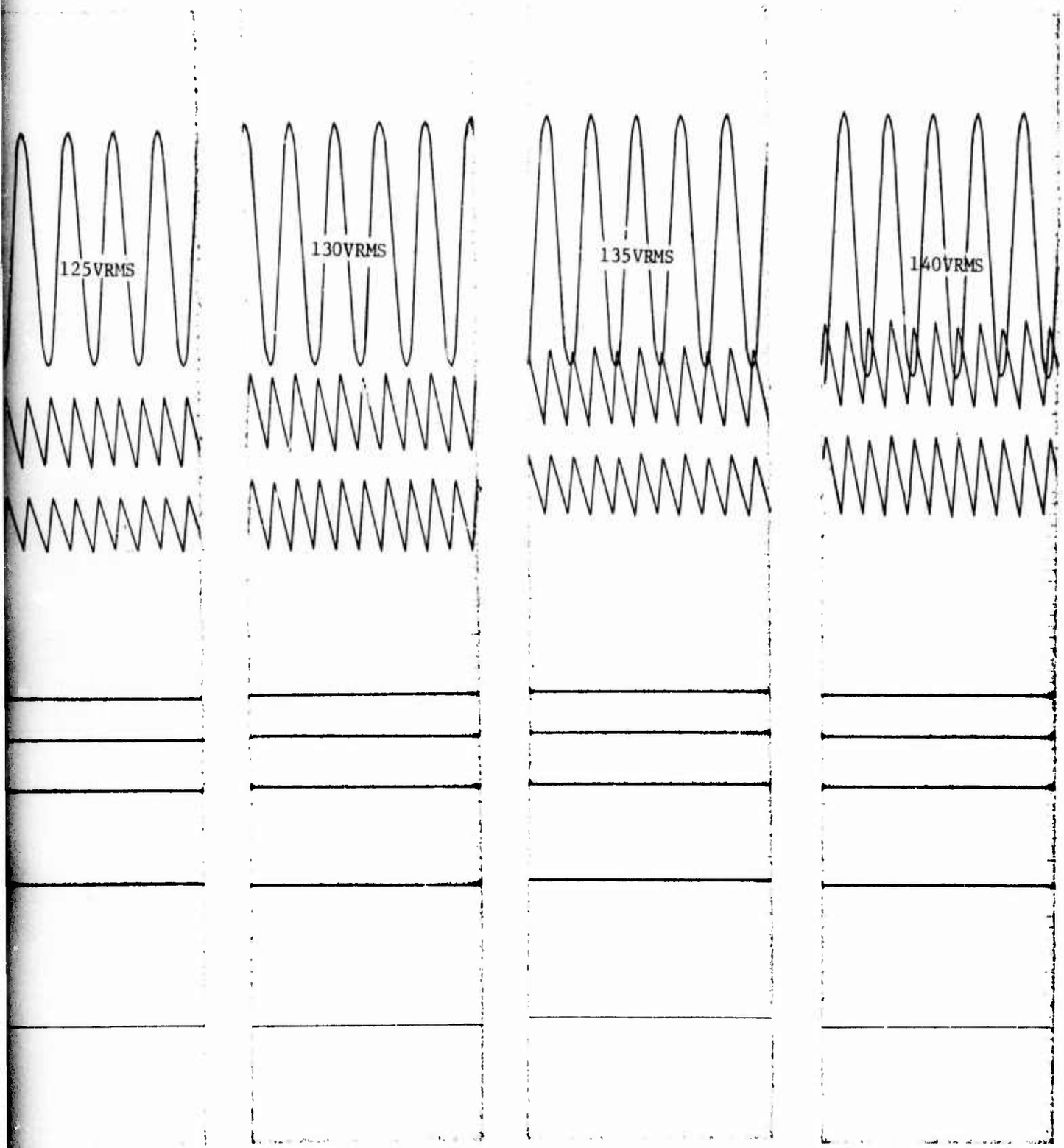


Figure 2. Steady state overvoltage in five (5) volt increments



dy state overvoltage in five (5) volt increments to 140 V RMS.

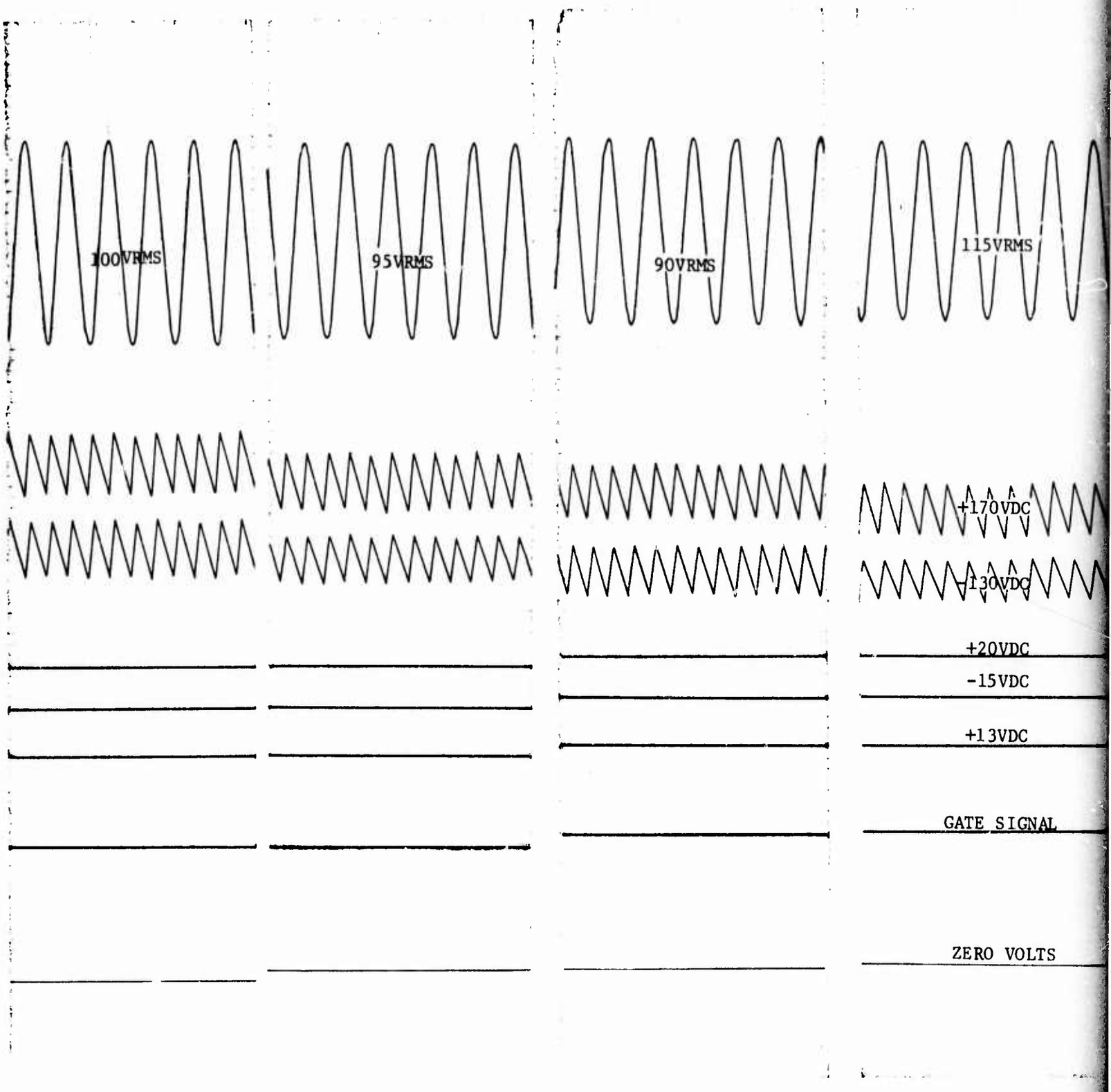
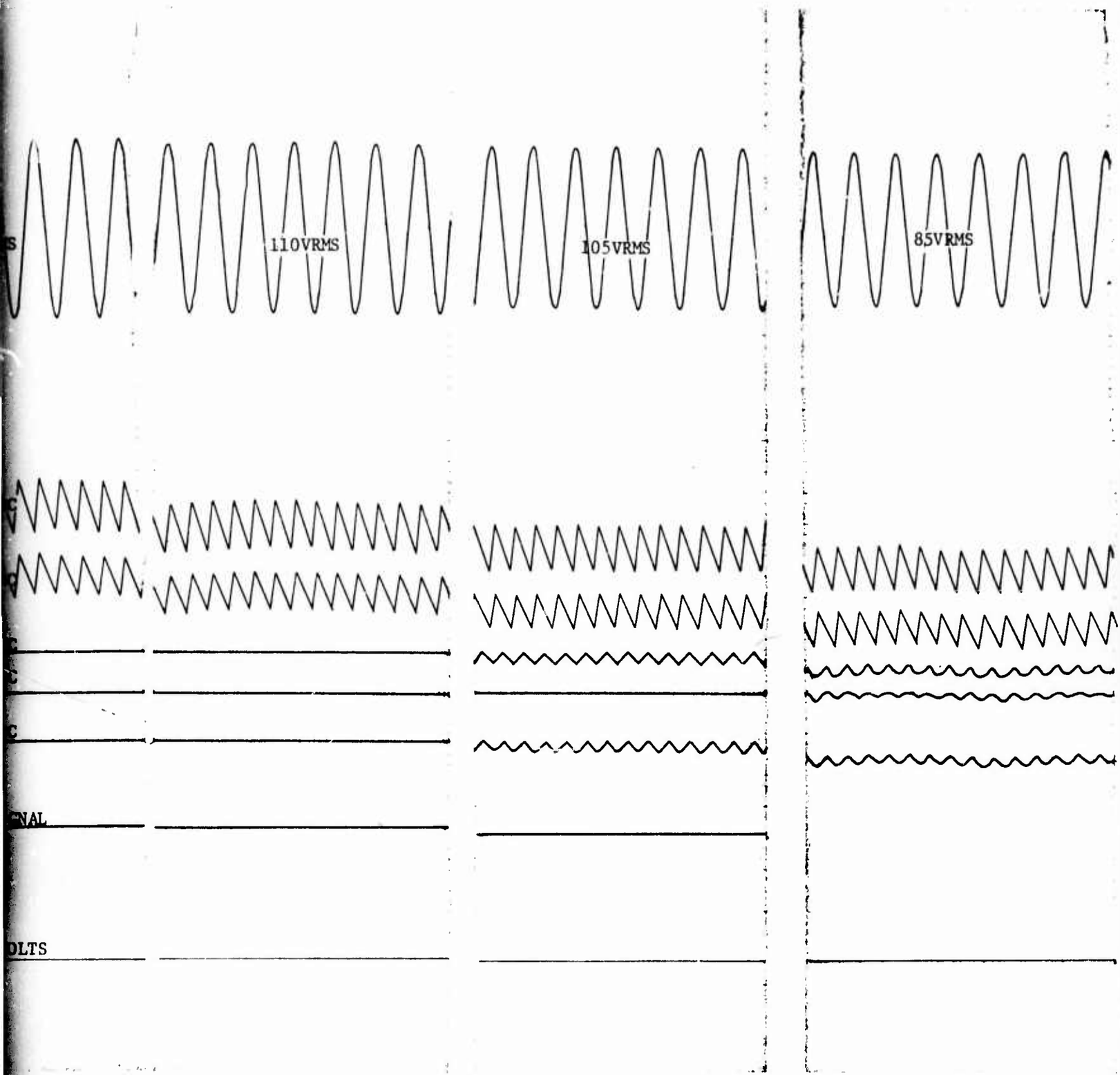


Figure 3. Steady state undervoltage in five (



n five (5) volt imcrements down to 85 V RSM.

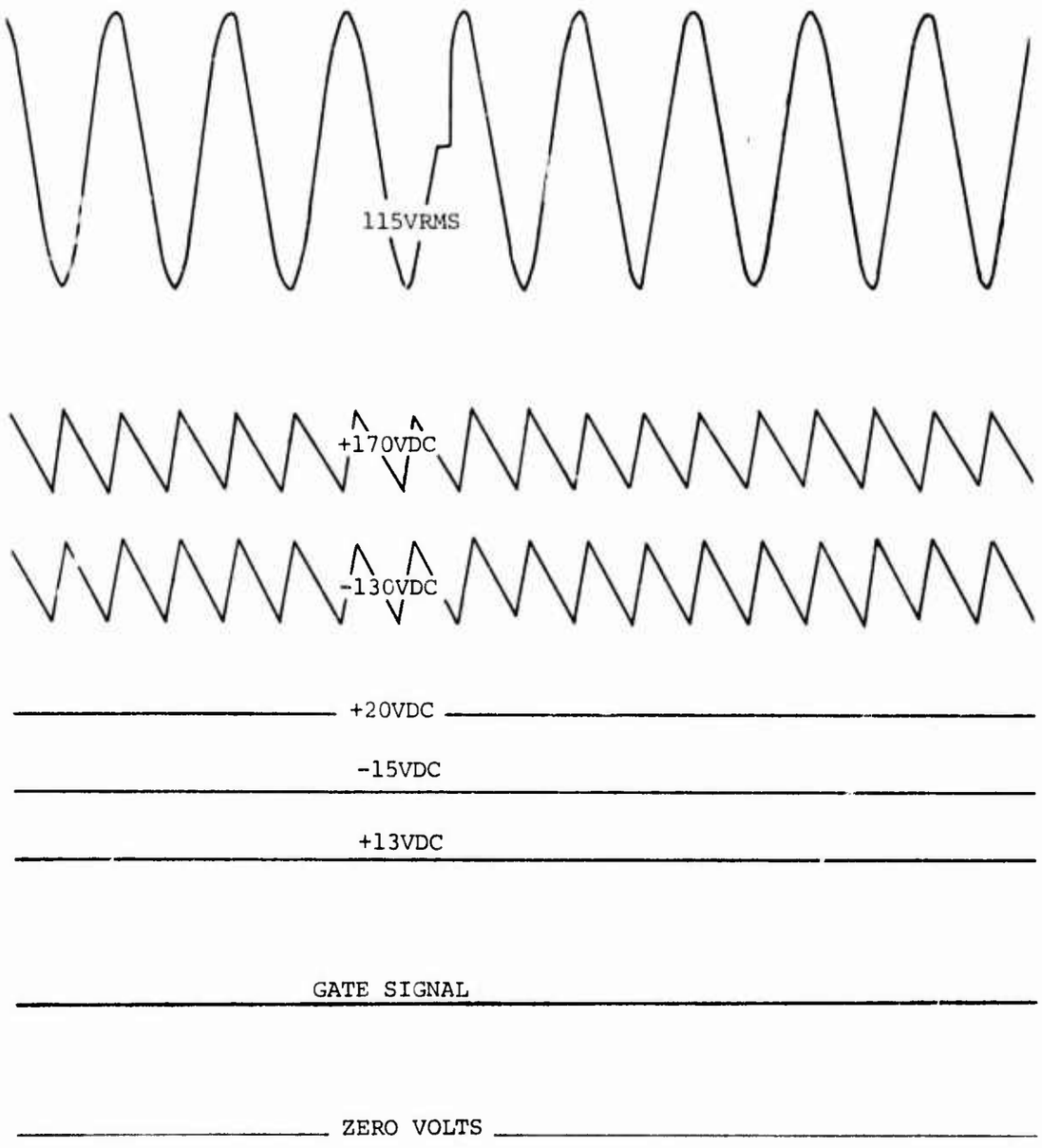


Figure 4. 1/8 cycle power outage.

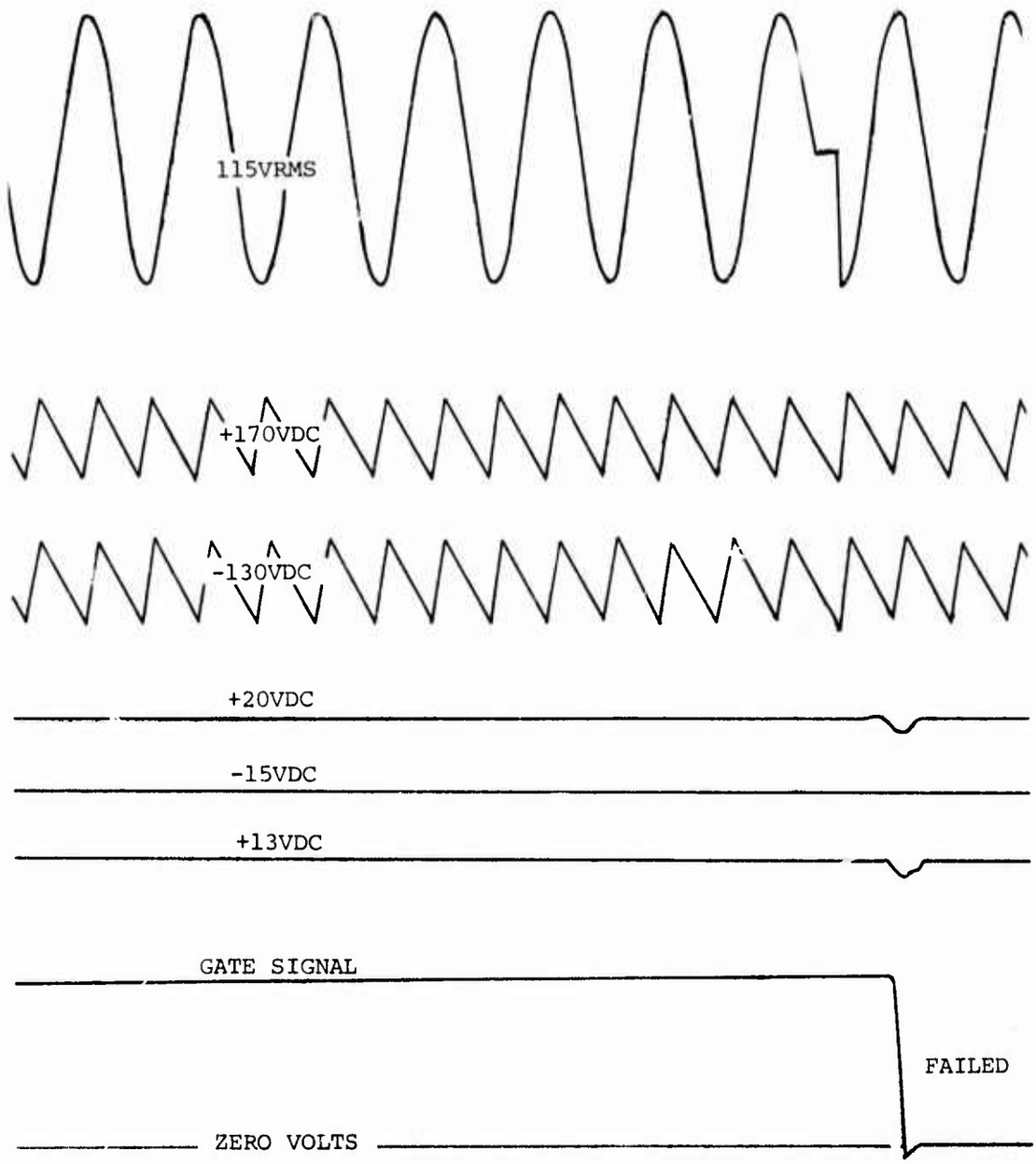


Figure 5. 1/4 cycle power outage.

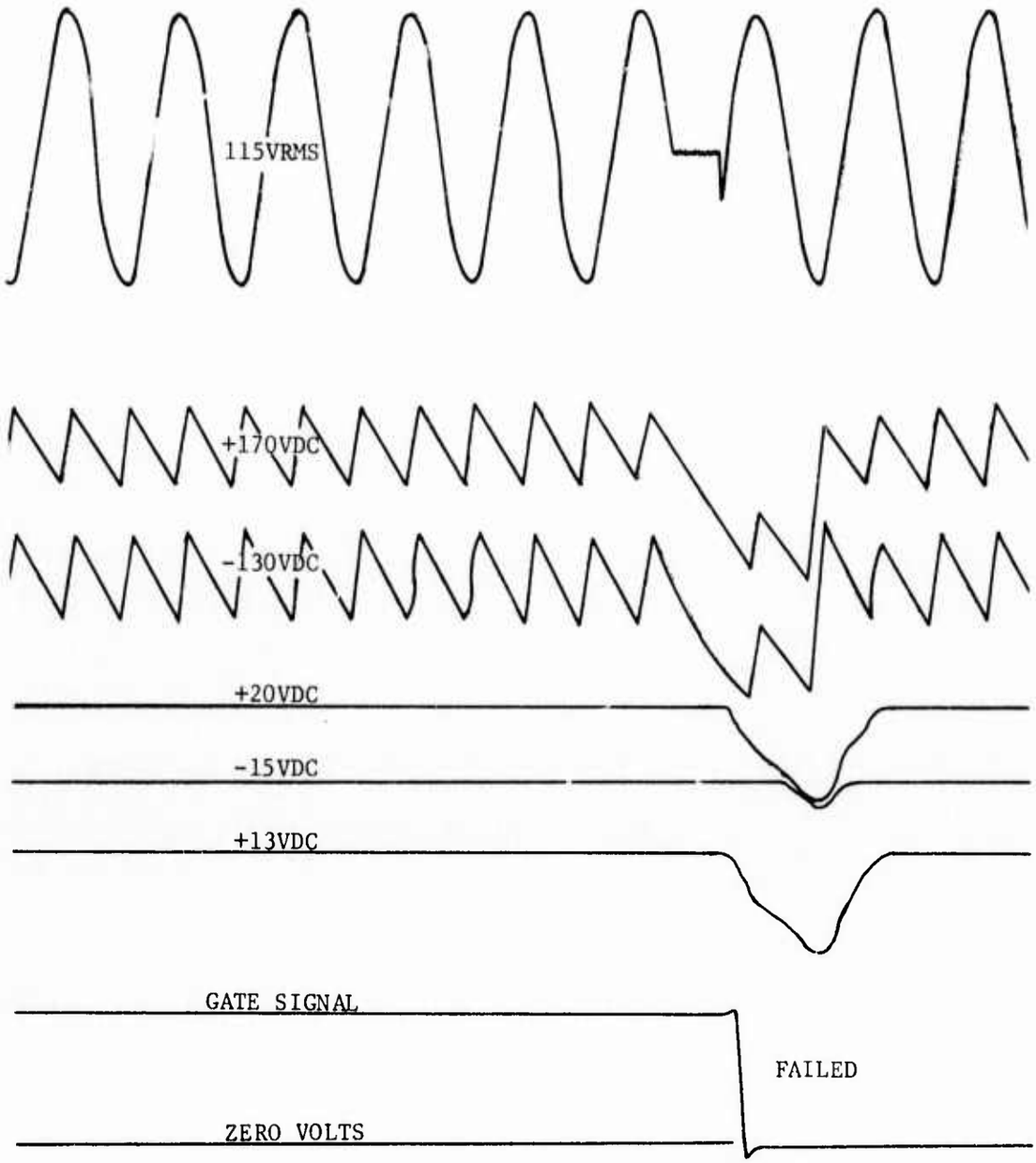


Figure 6. 1/2 cycle power outage.

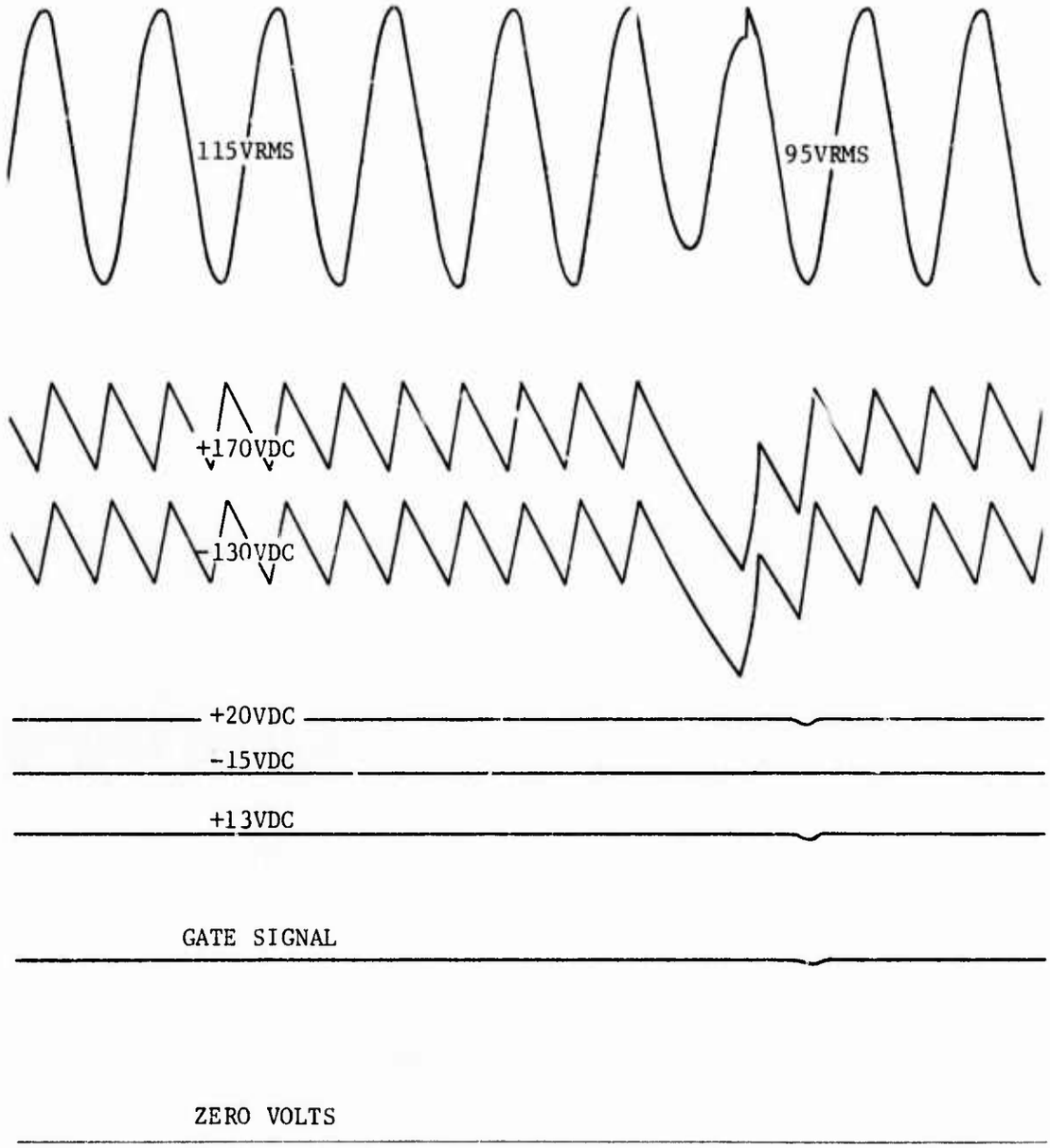


Figure 7. 1 cycle undervoltage.

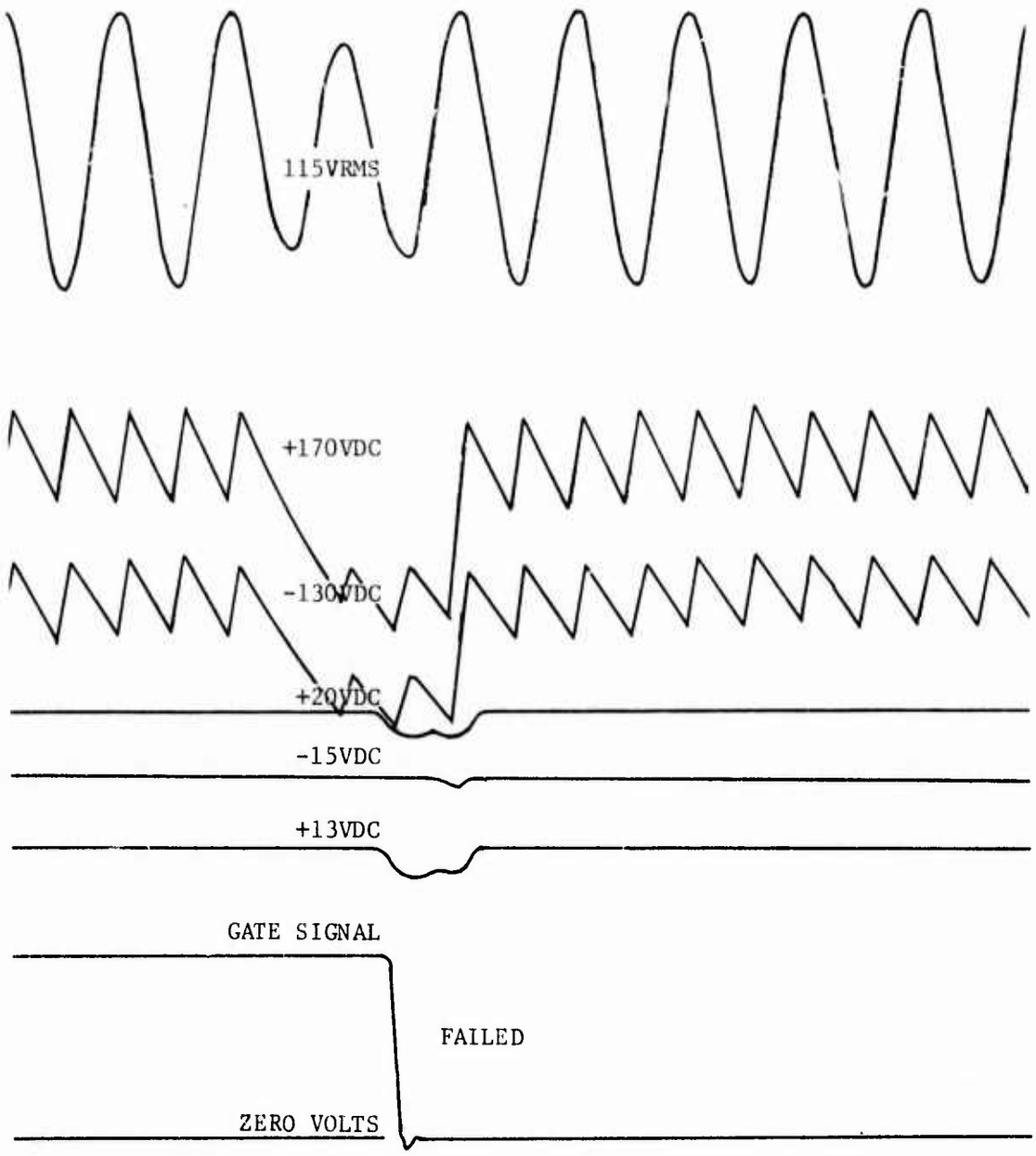


Figure 8. 1 1/2 cycle undervoltage.

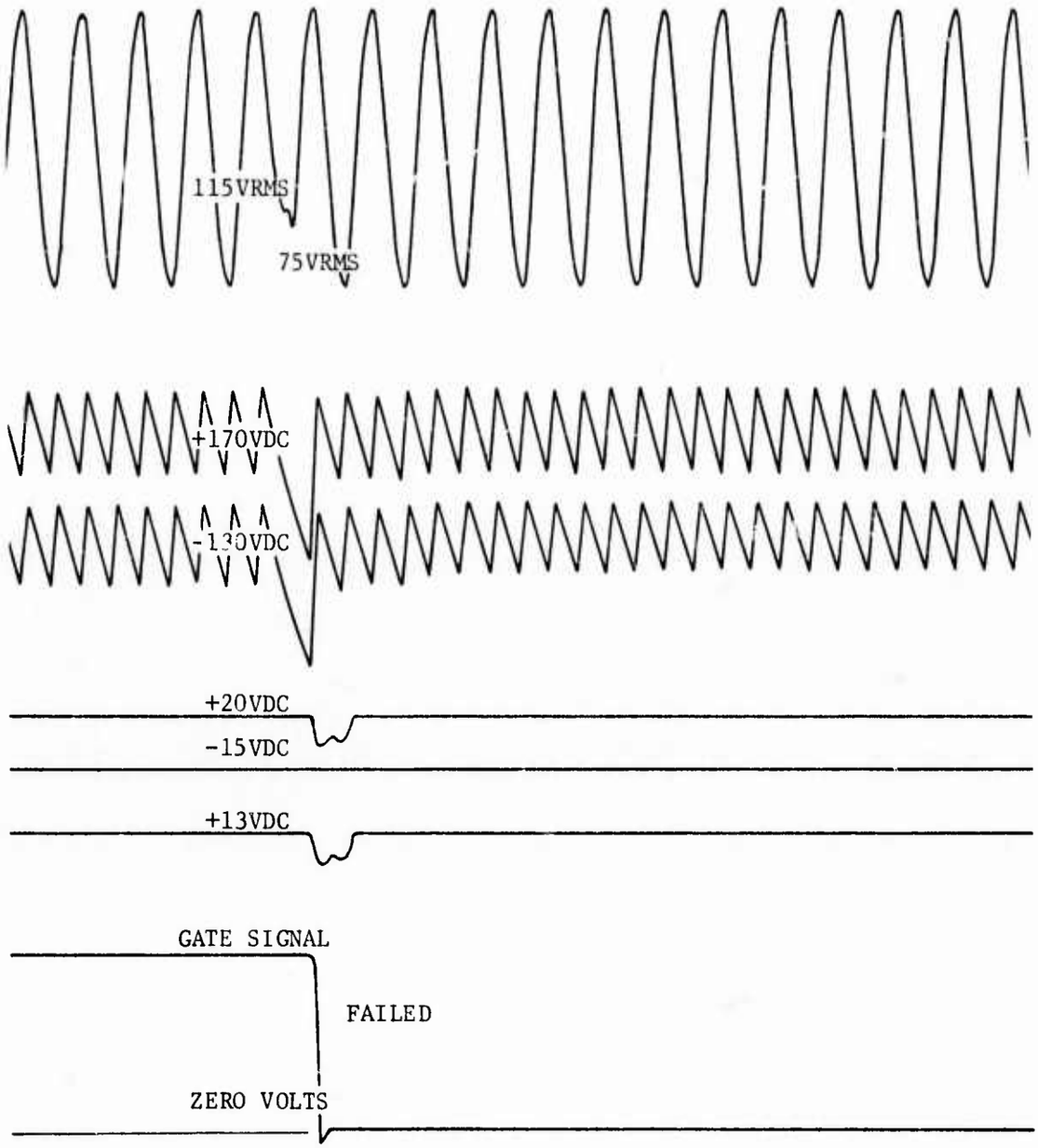


Figure 9. 1/2 cycle undervoltage.

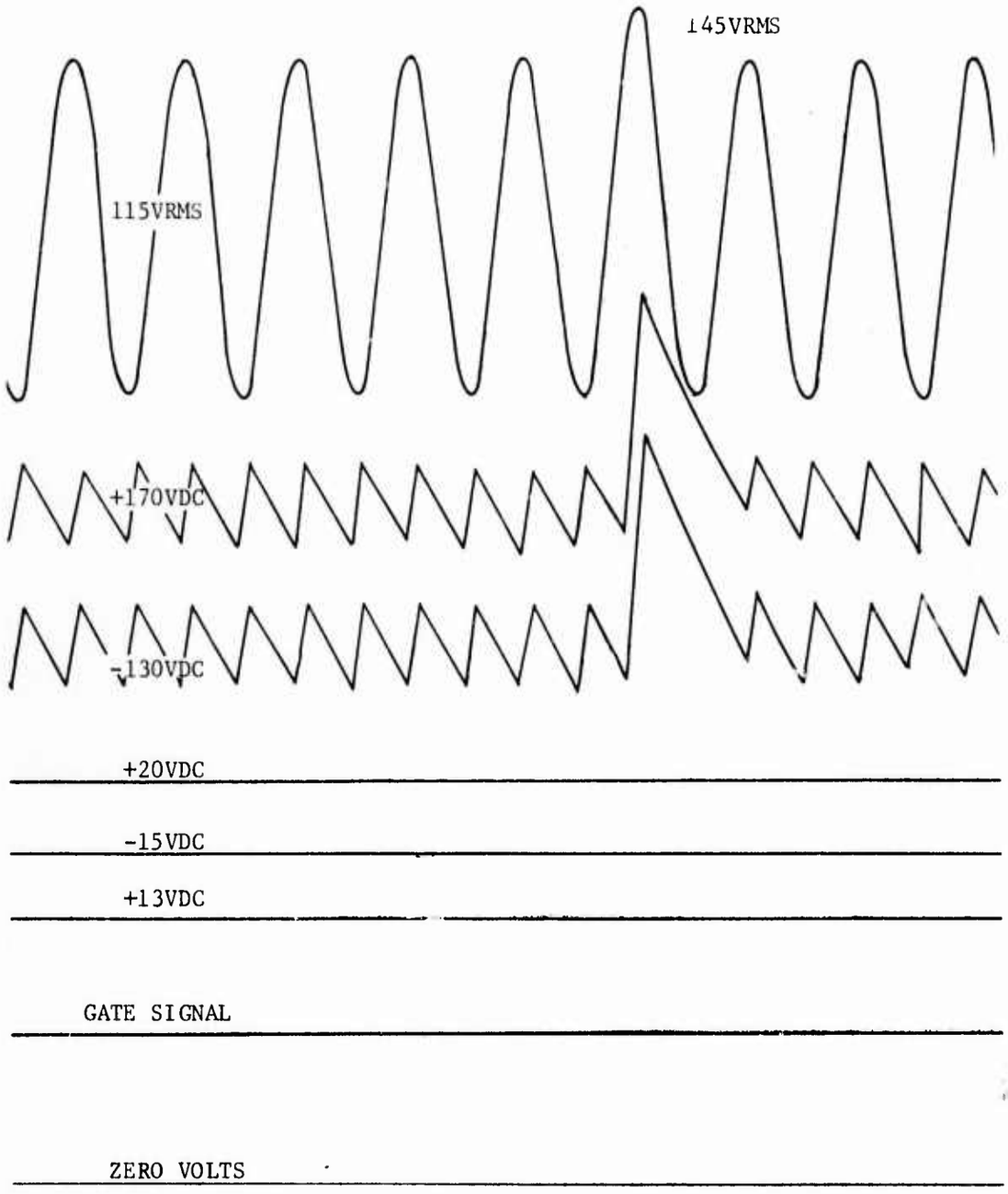


Figure 10. 1/2 cycle overvoltage.

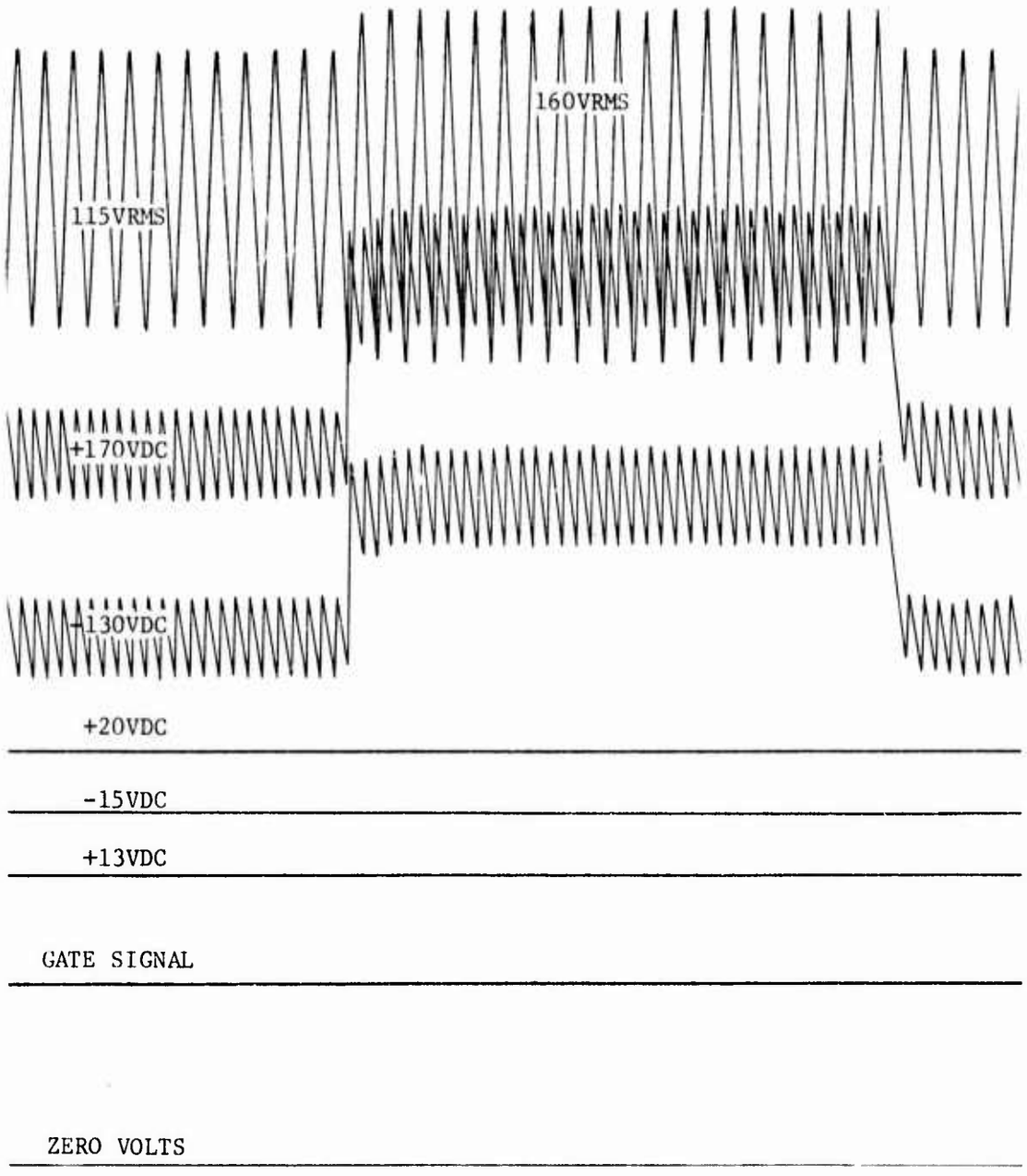


Figure 11. 20 cycle overvoltage.

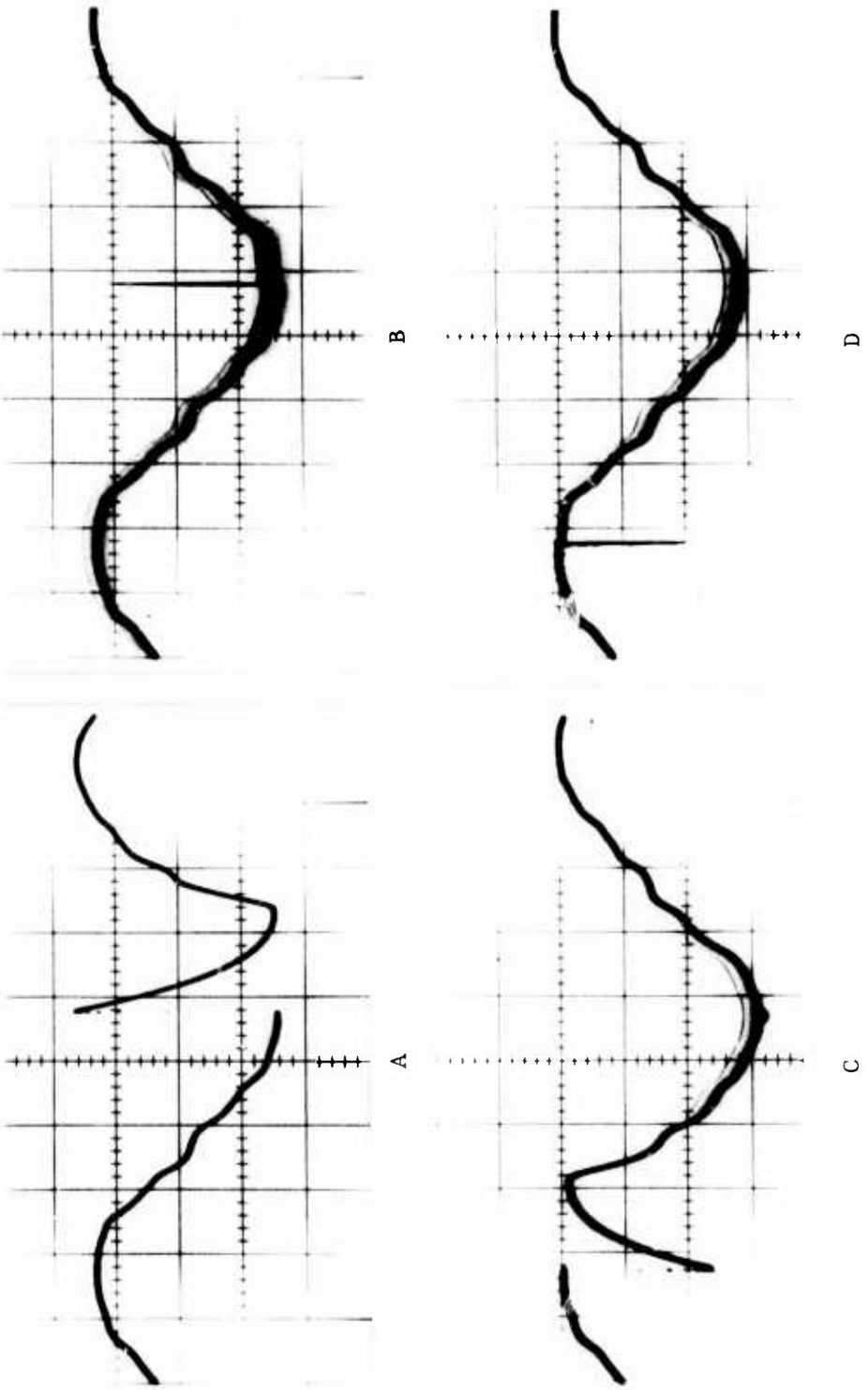


Figure 12. Negative polarity pulse transients.

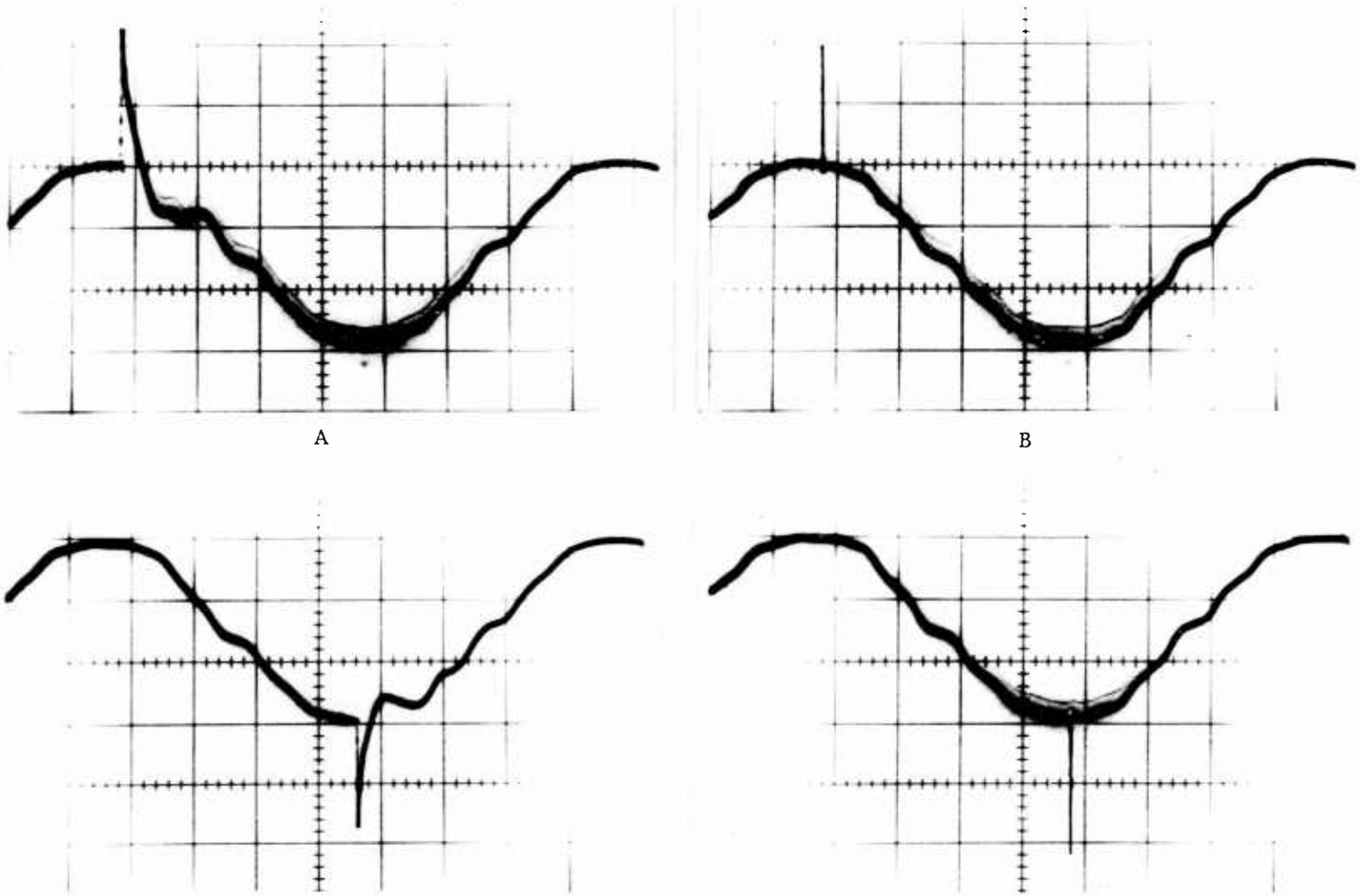


Figure 13. Positive polarity pulse transients.

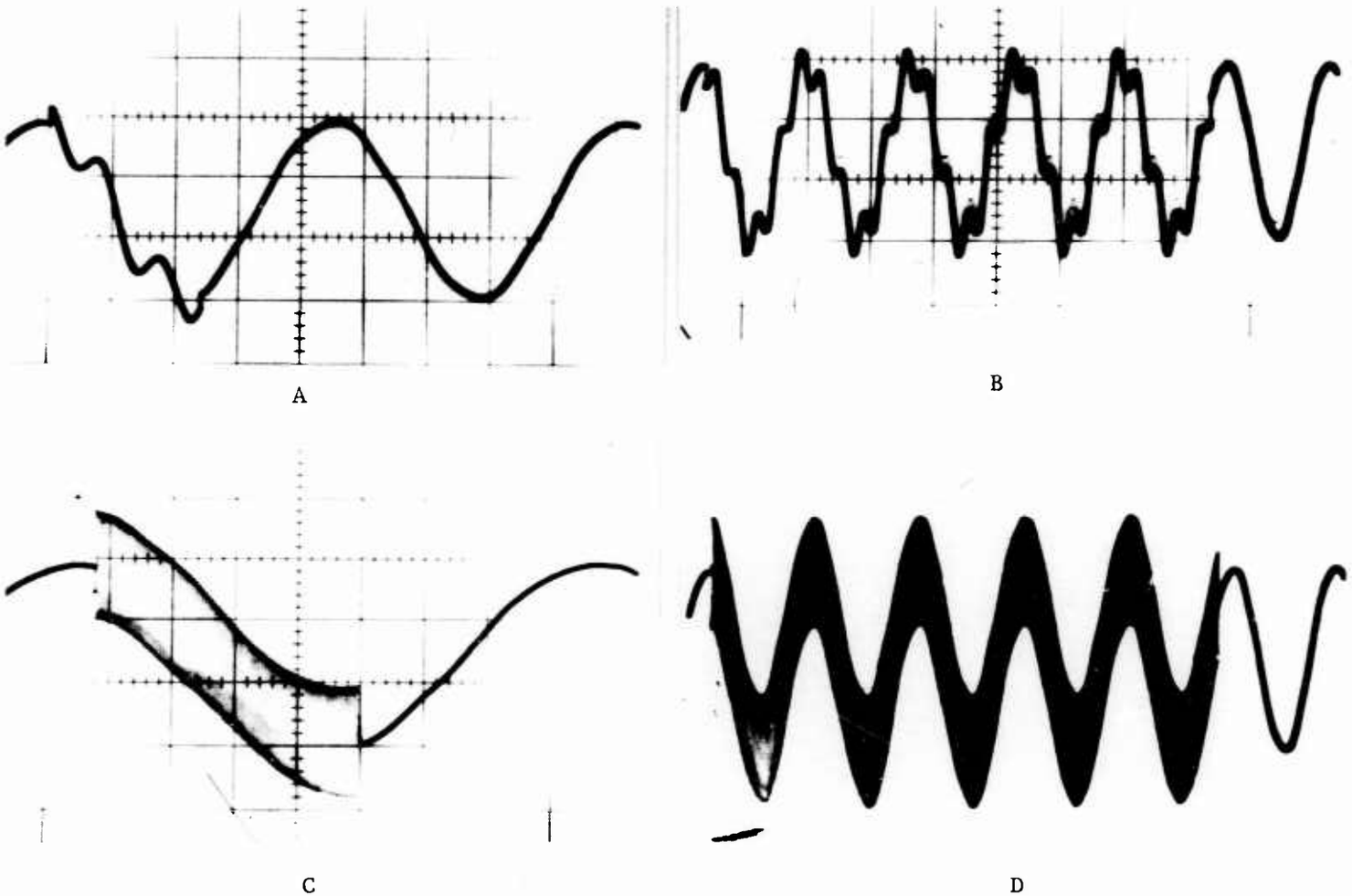


Figure 14. Superimposed high frequency on 60 hz power.

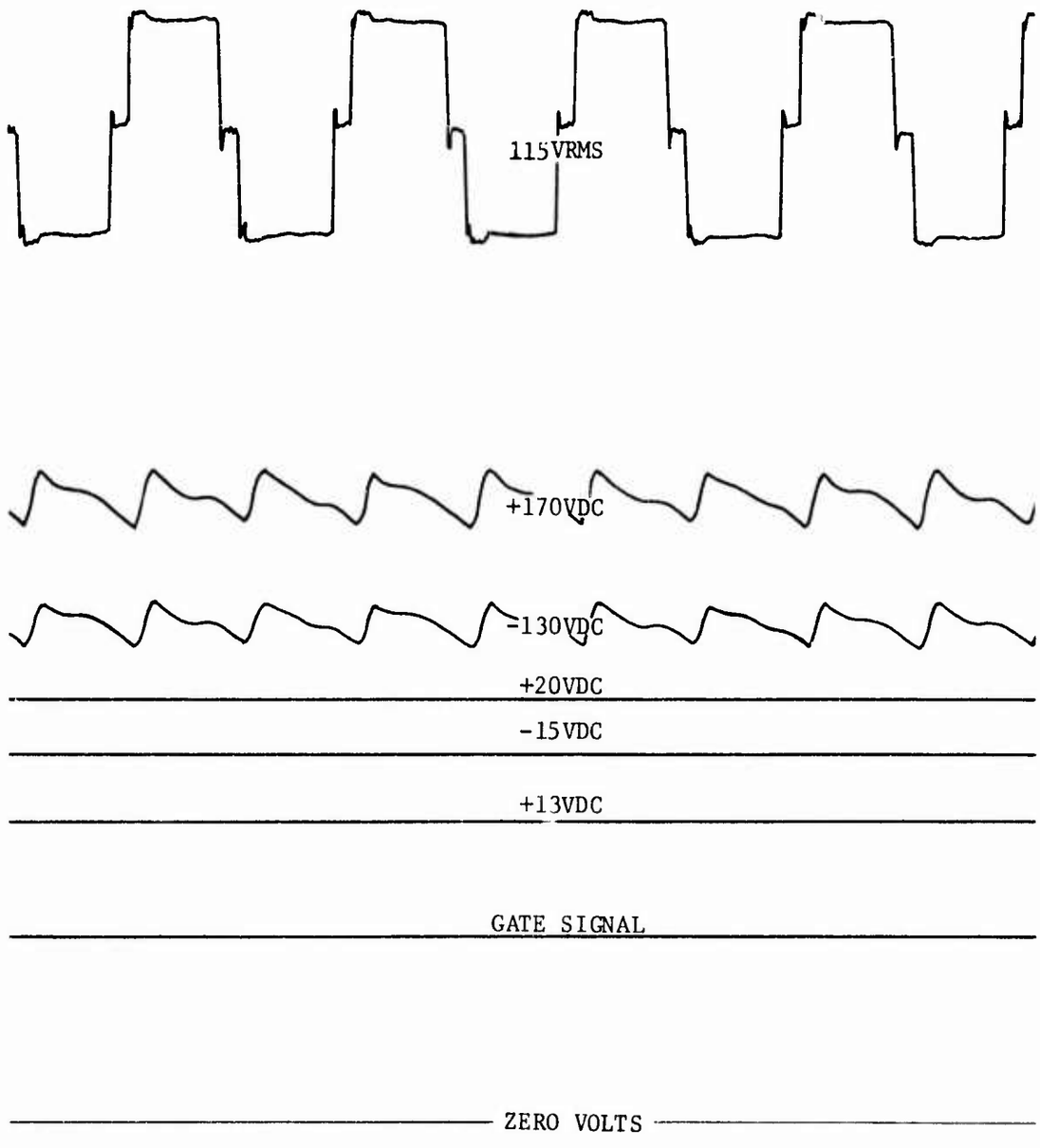


Figure 15. Normal operation with squarewave input power.

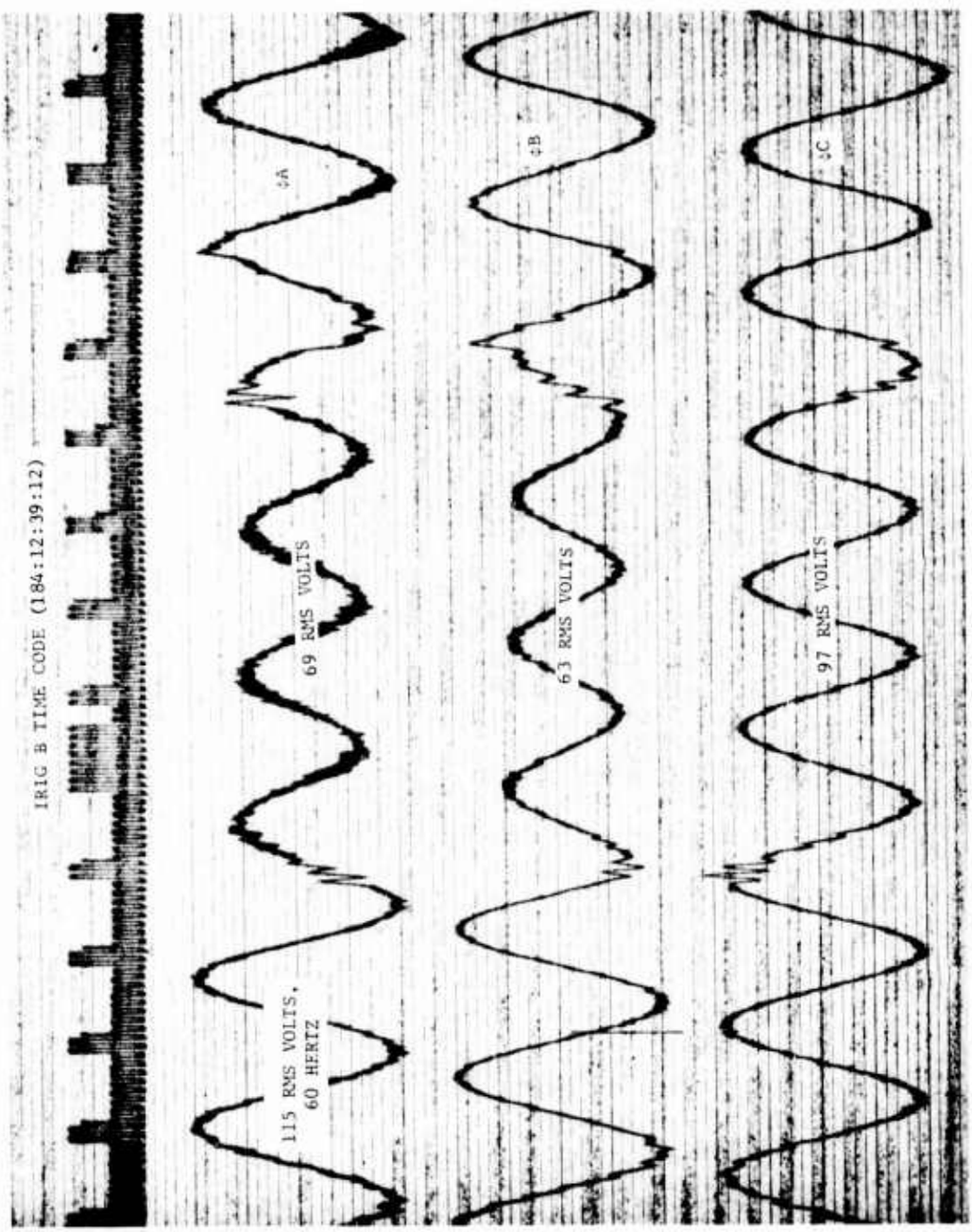


Figure 16. Four (4) cycle undervoltage cause unknown.

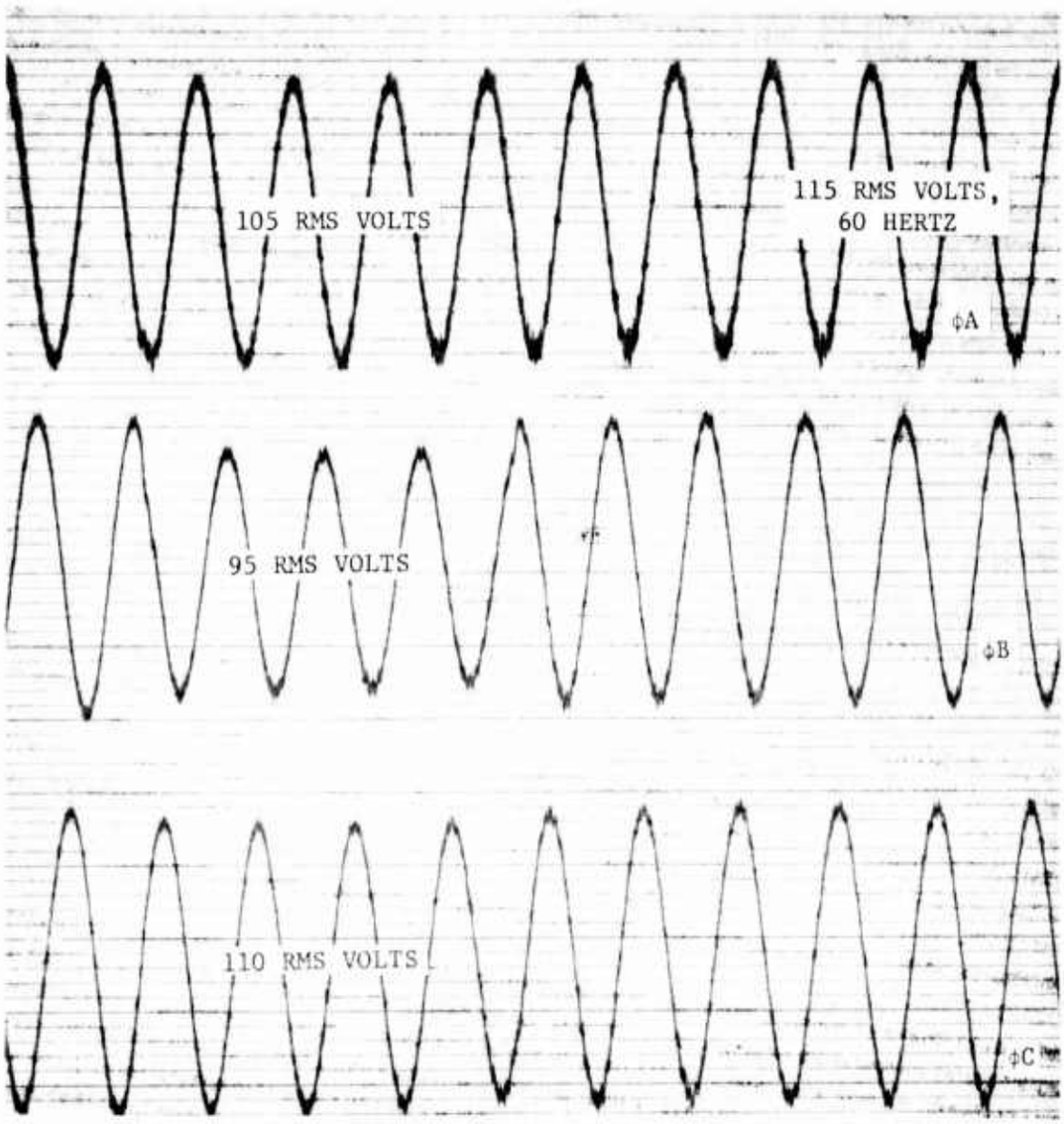


Figure 17. Momentary voltage dip cause unknown.

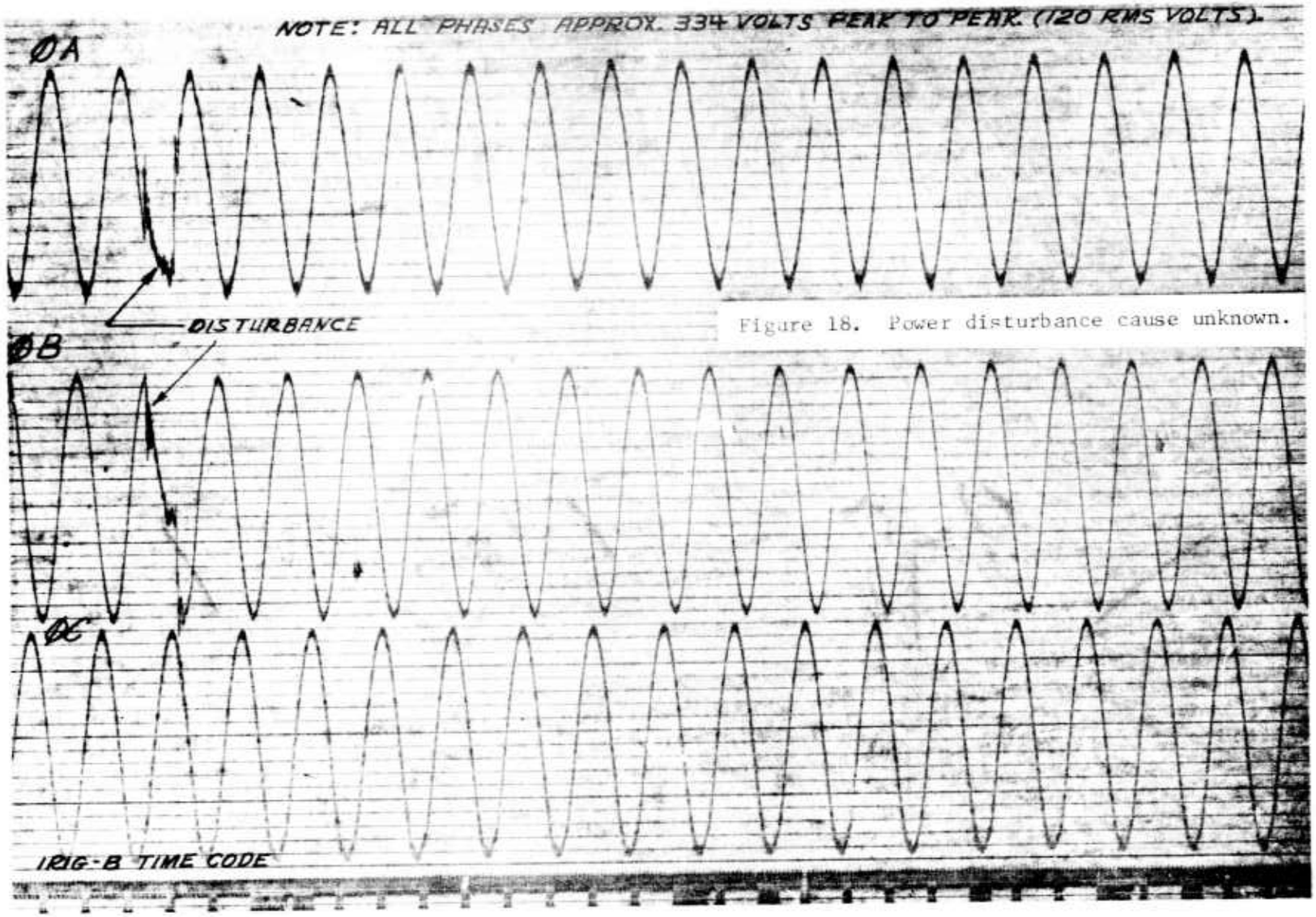


Figure 18. Power disturbance cause unknown.

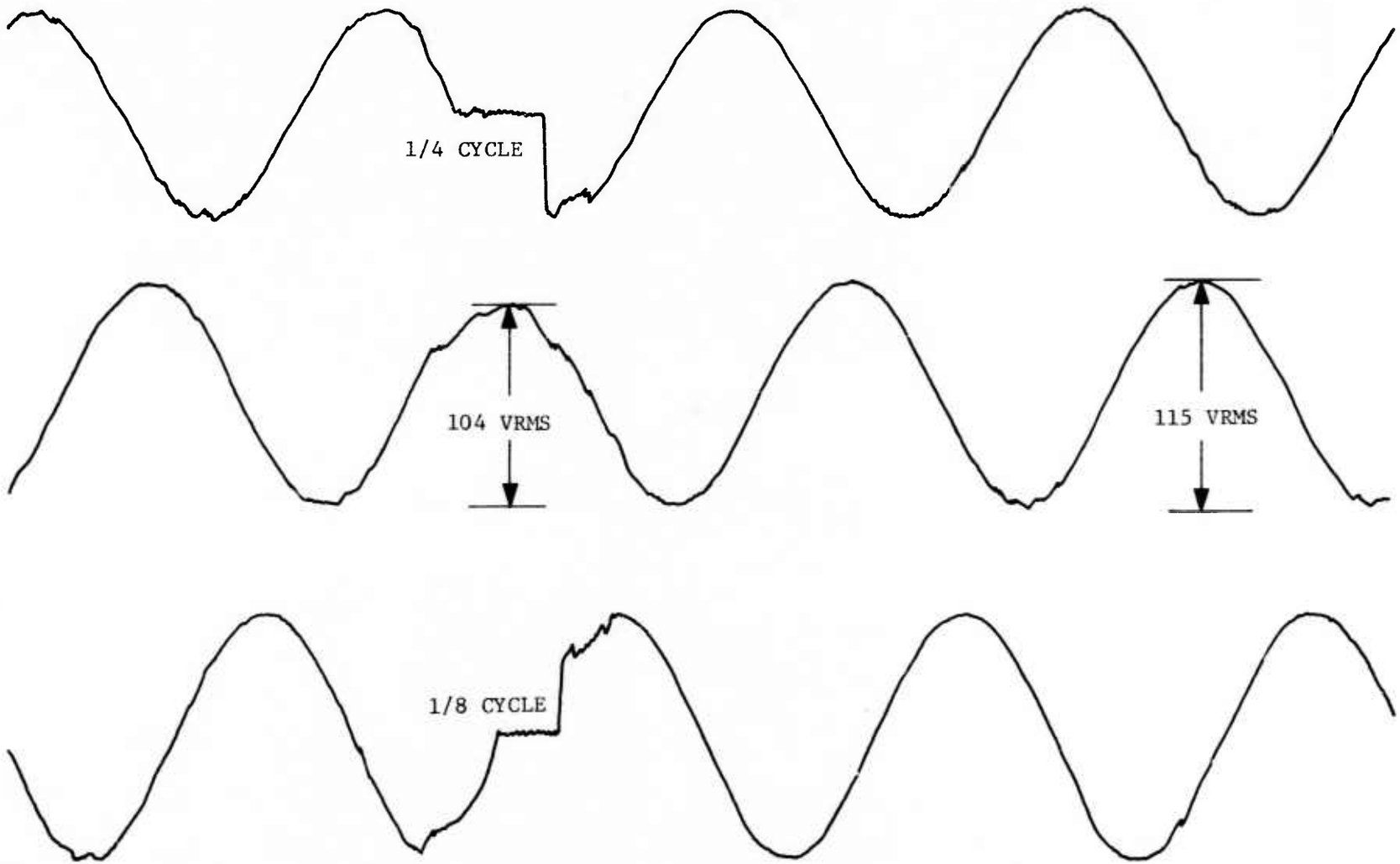


Figure 19. Momentary Power Outage and Voltage Dip.

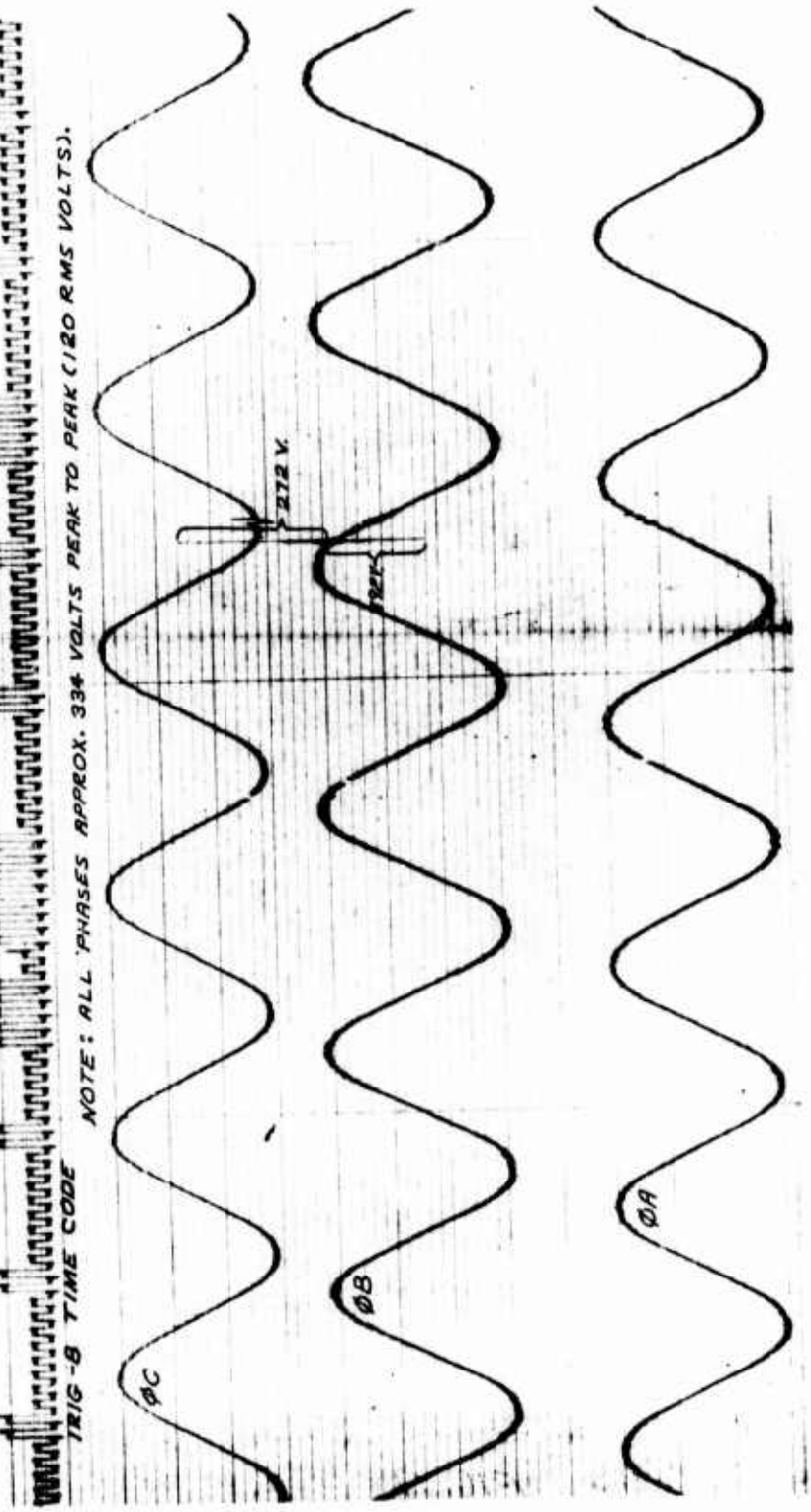


Figure 20. Pulse transient cause unknown.

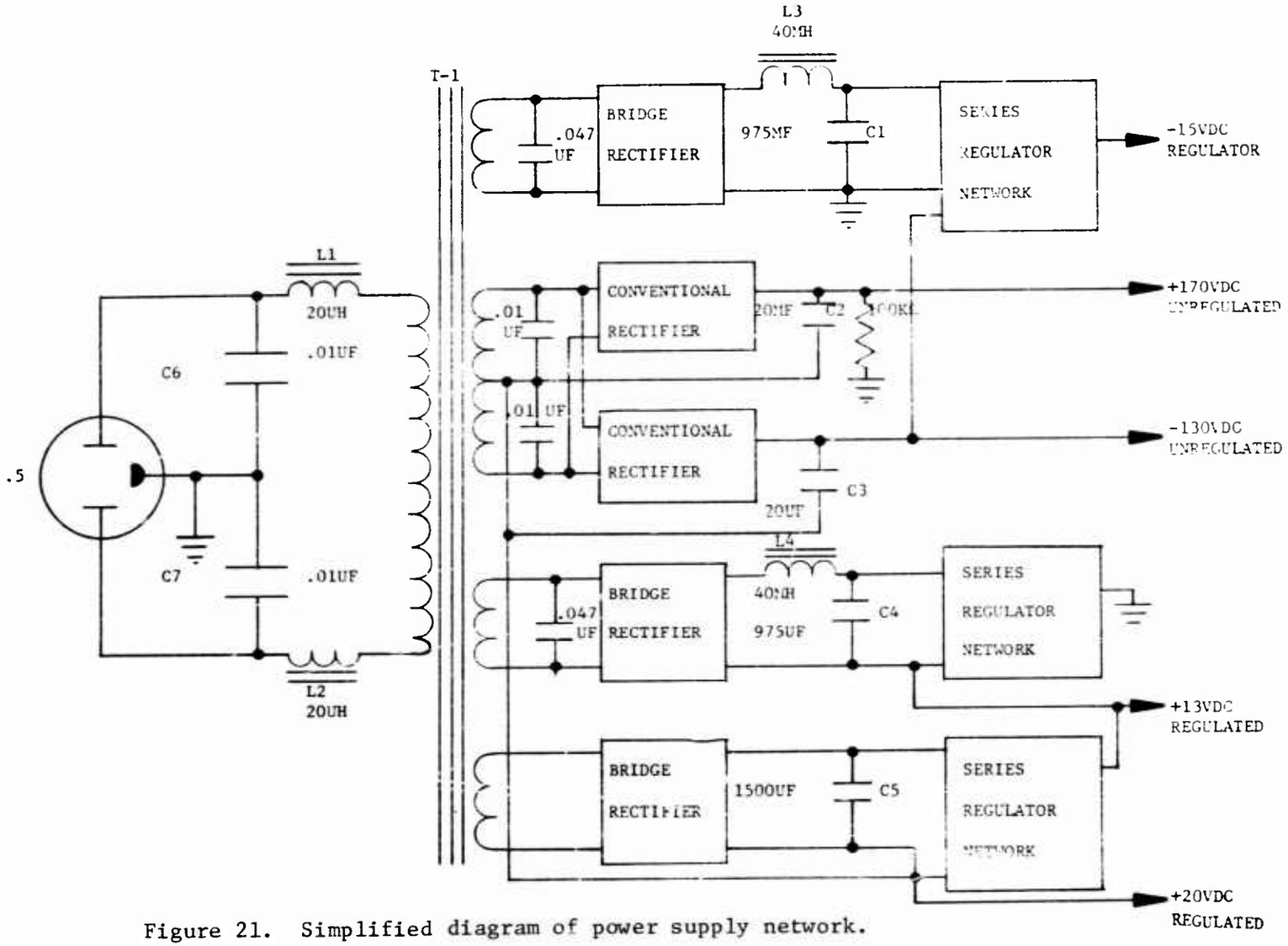


Figure 21. Simplified diagram of power supply network.

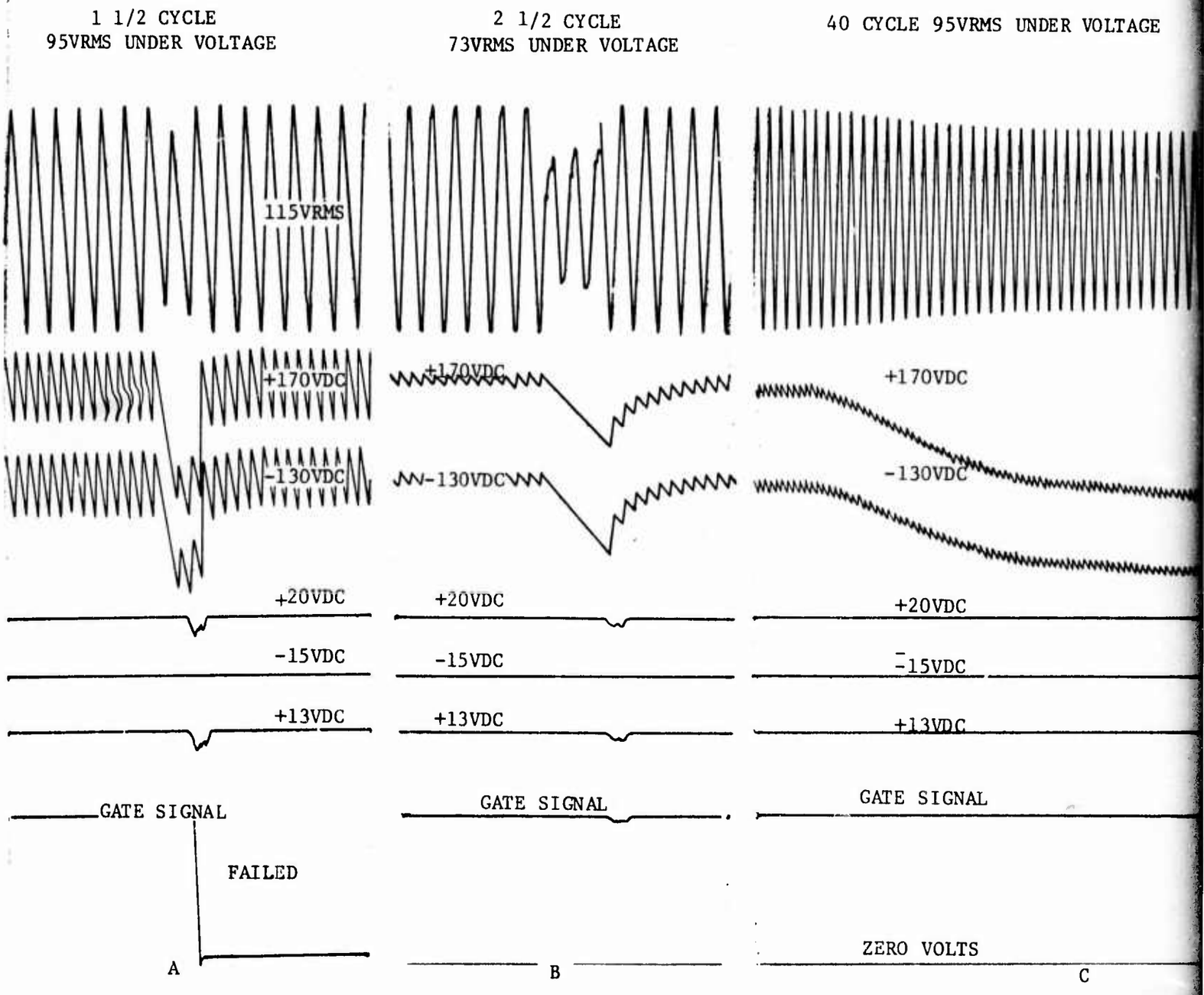
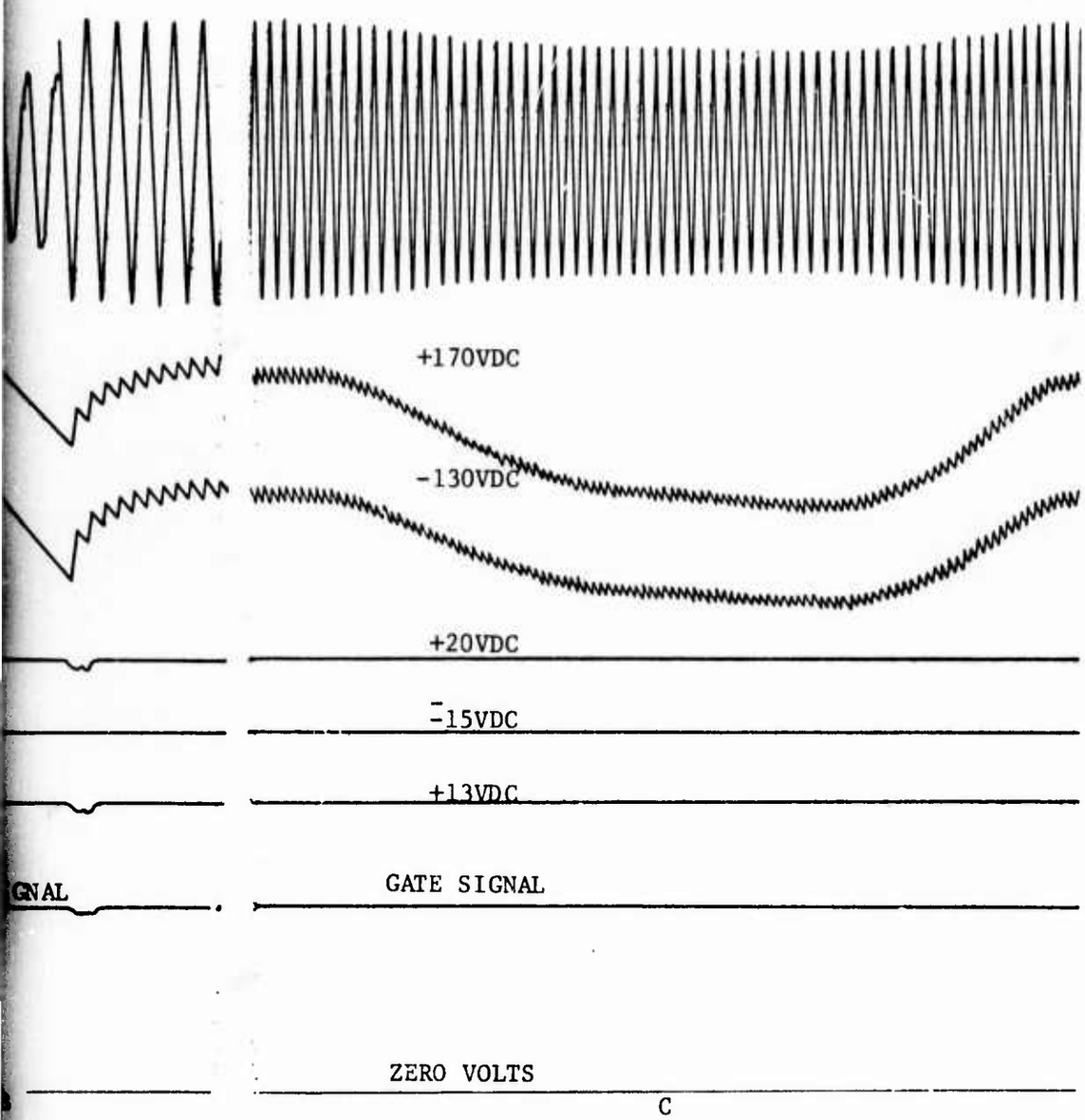


Figure 22. Momentary undervoltages.



2. Momentary undervoltages.

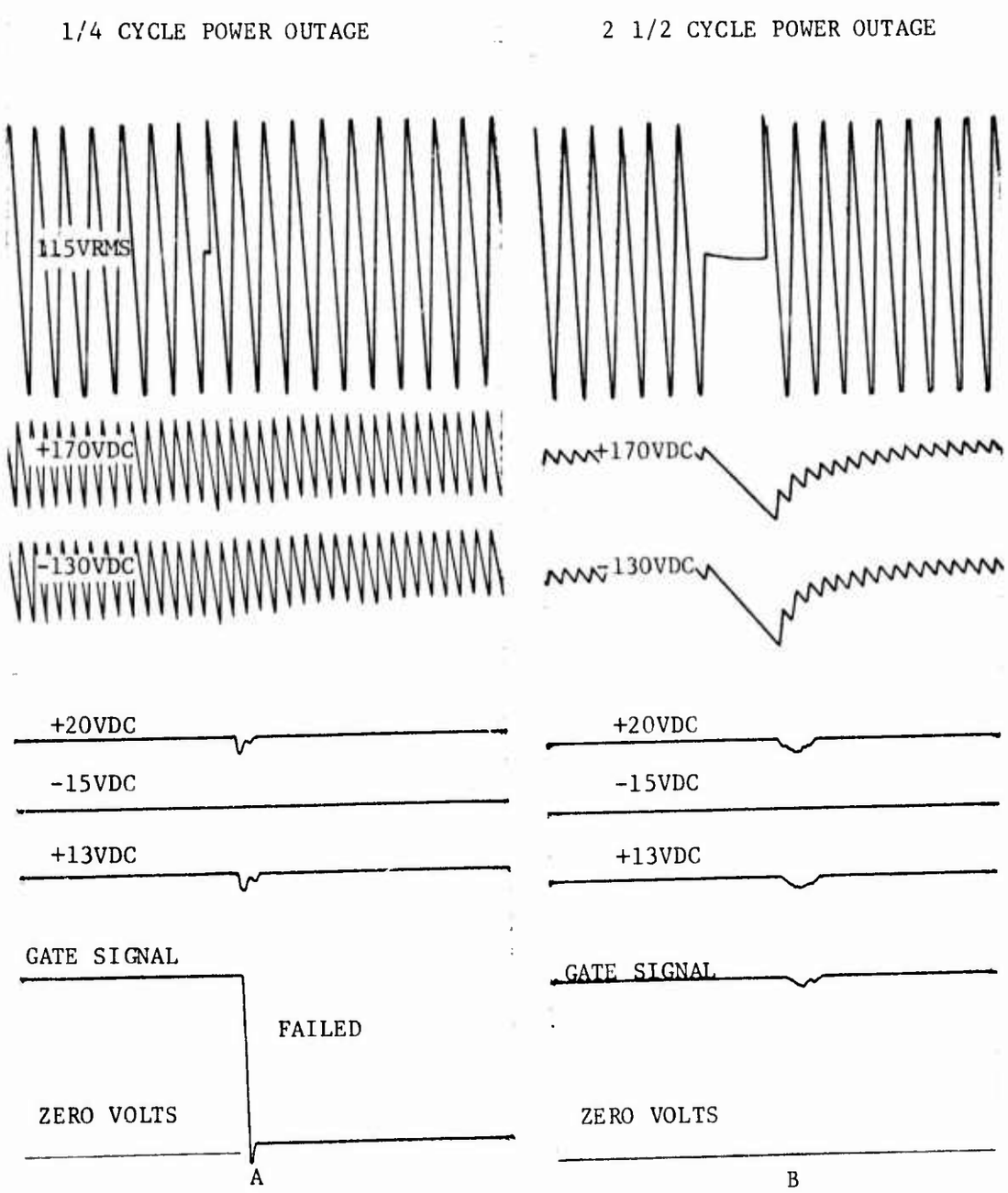


Figure 23. Momentary power outages.

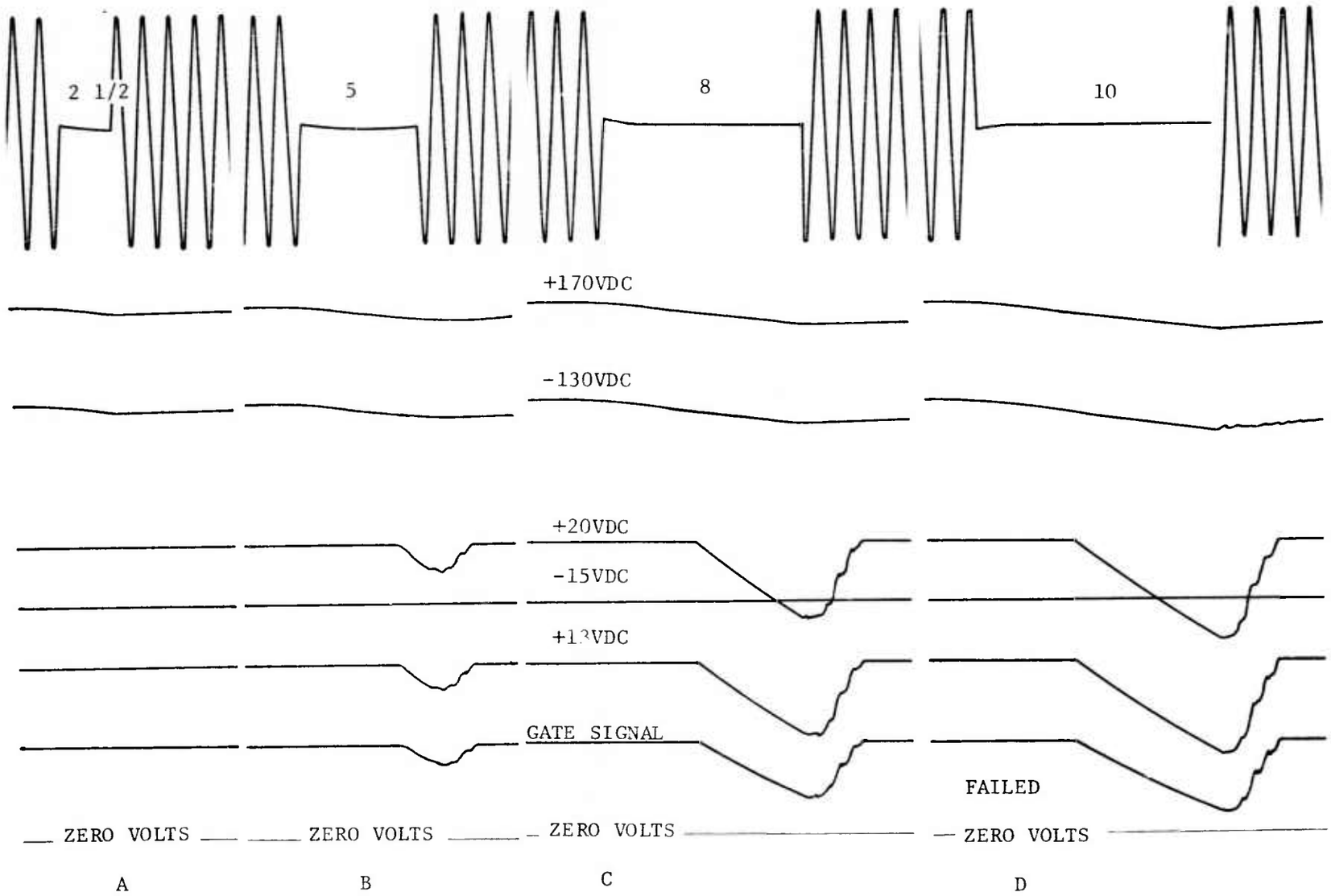


Figure 24. Momentary power outages.

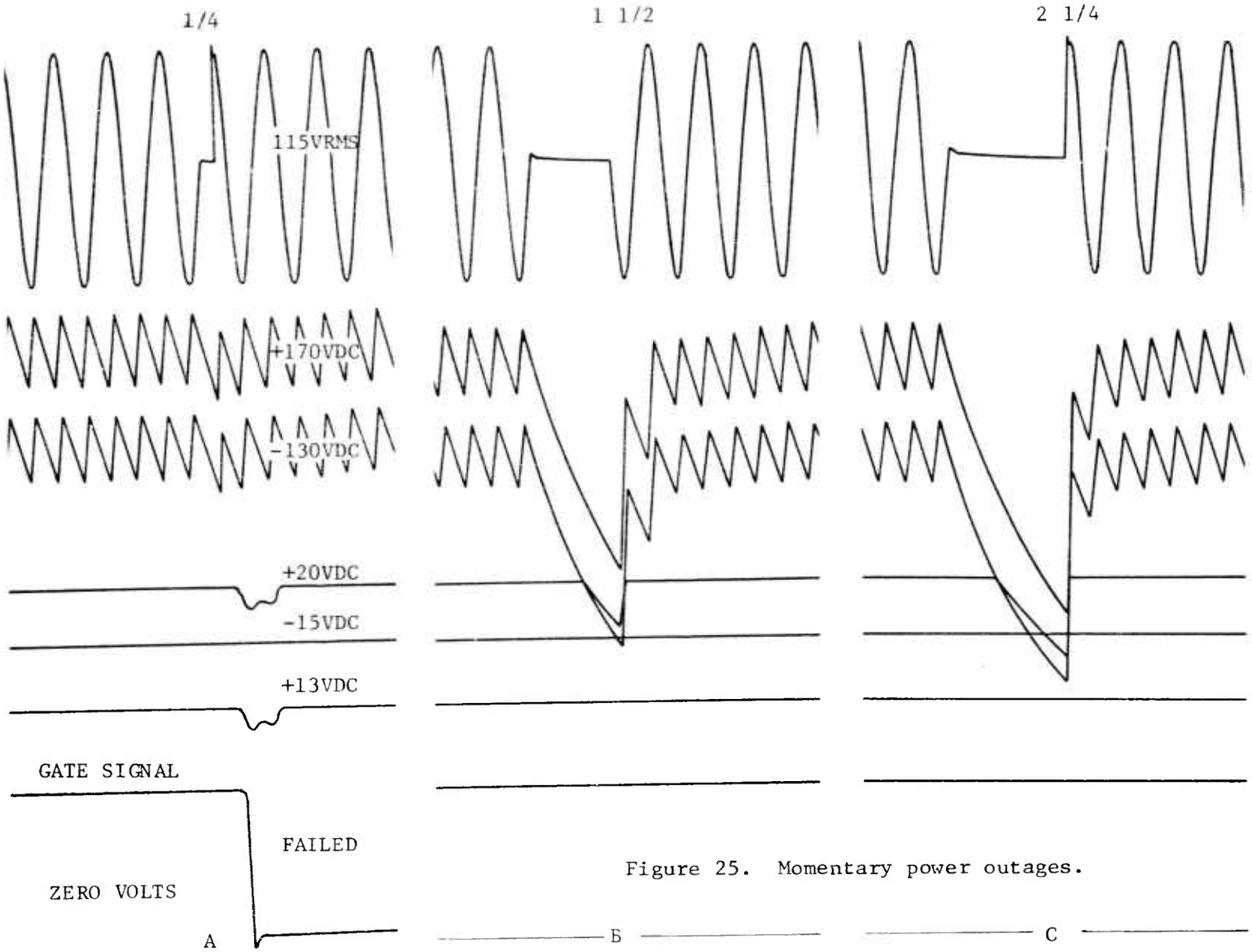


Figure 25. Momentary power outages.

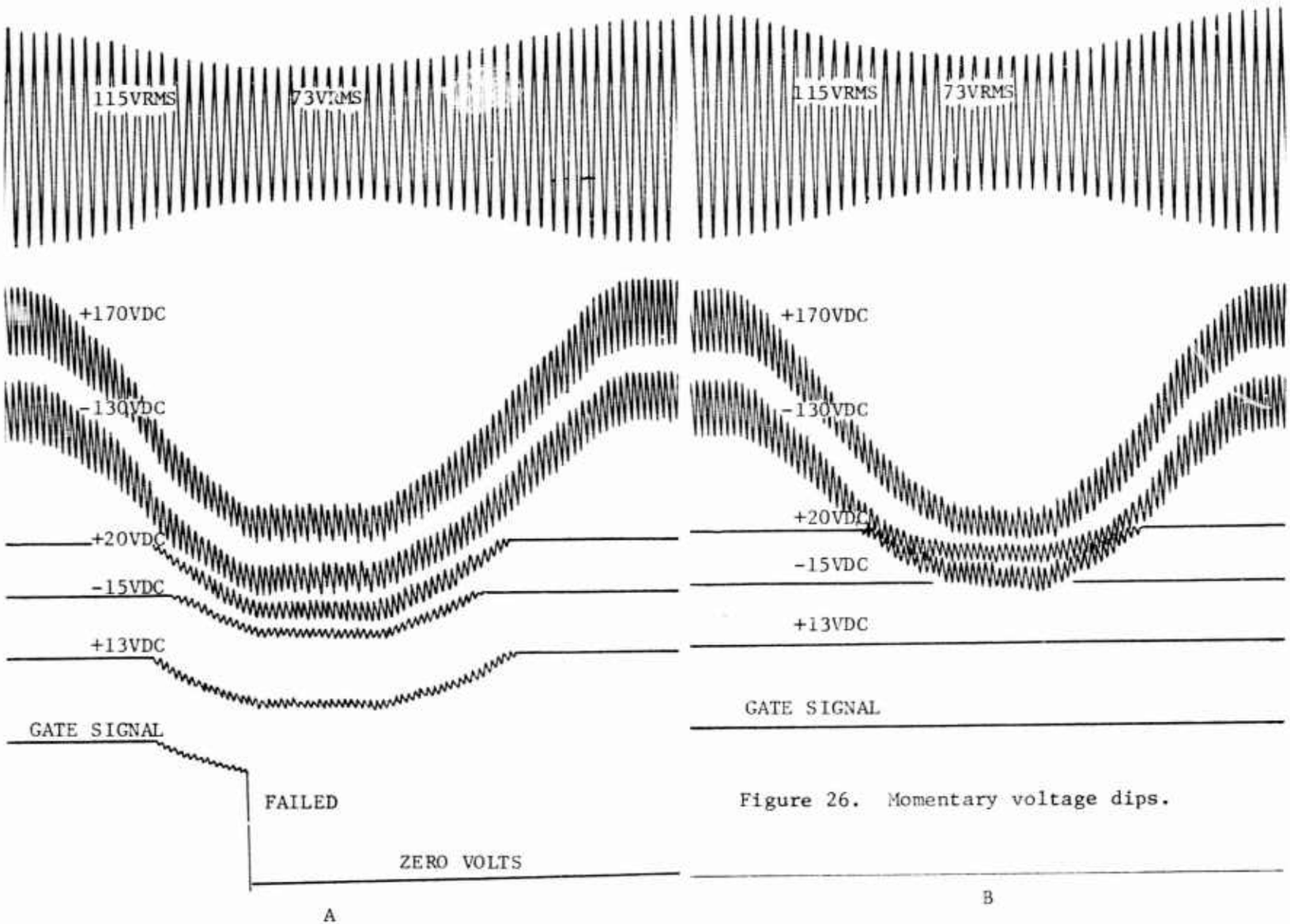
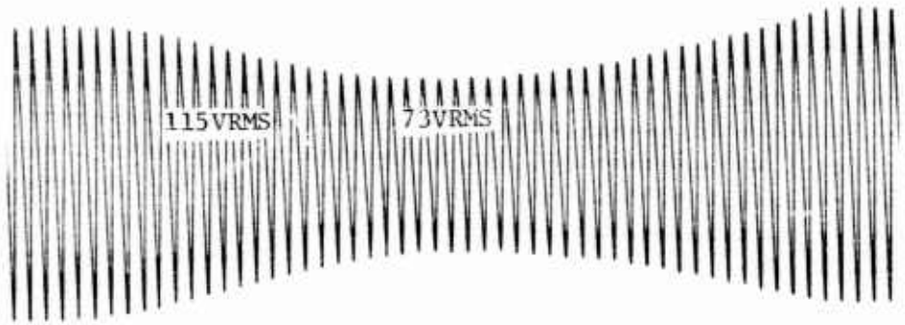


Figure 26. Momentary voltage dips.



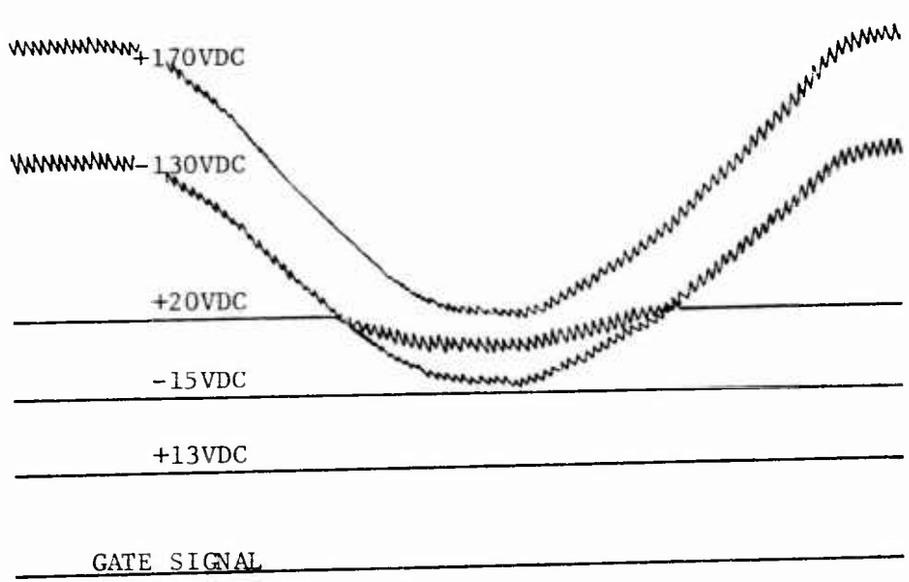
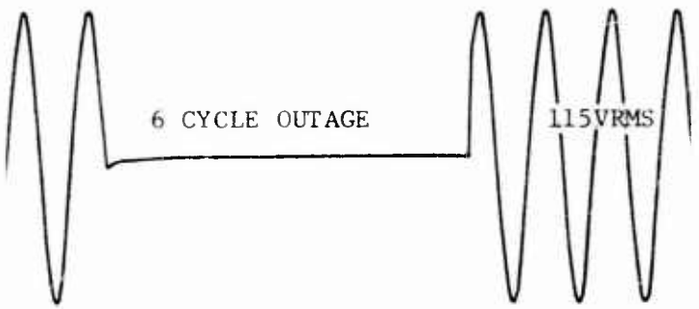


Figure 27a. 40 cycle voltage dip.



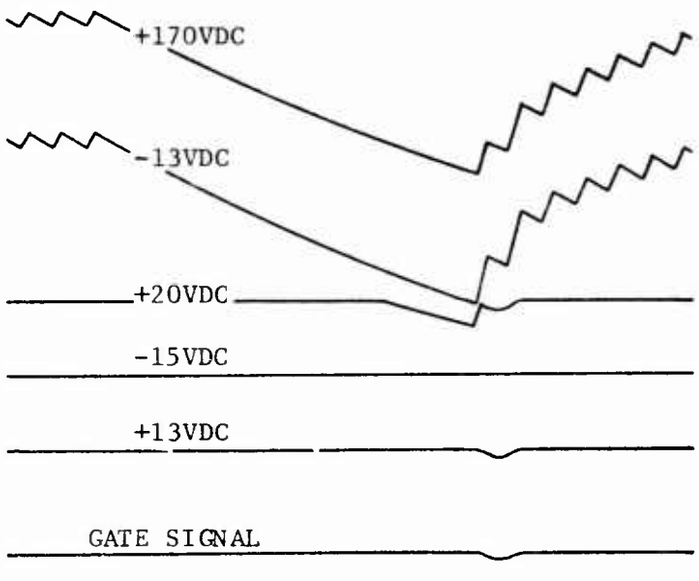
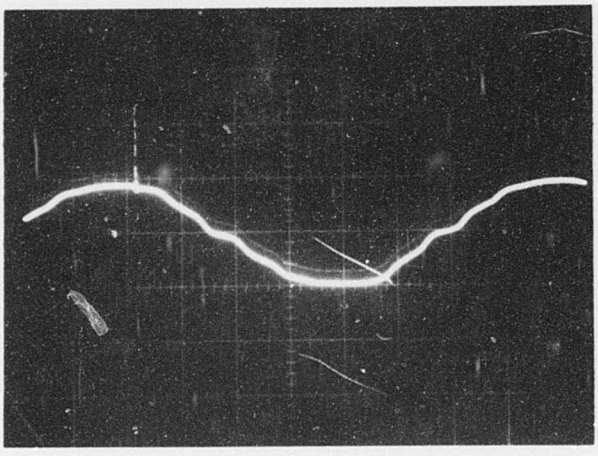
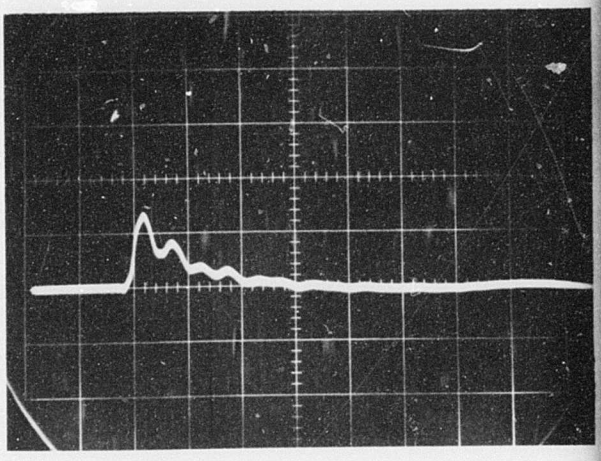


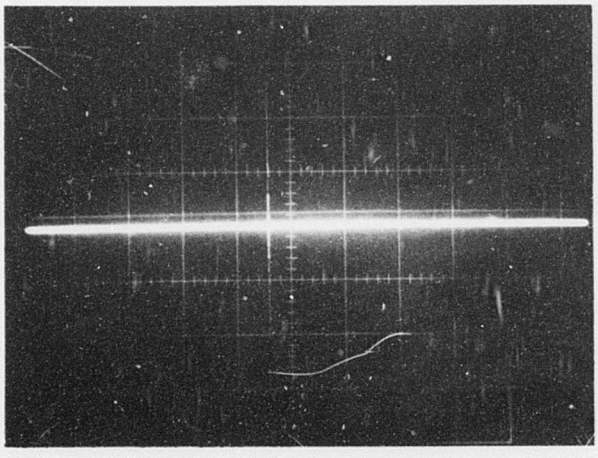
Figure 27b. 6 cycle power outage.



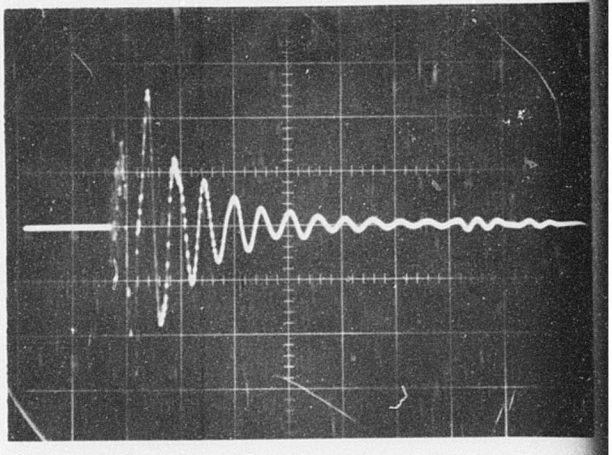
A



B

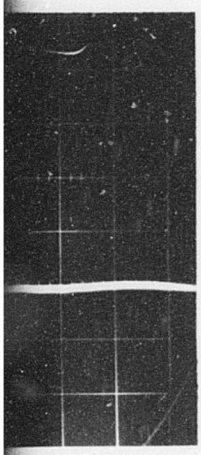


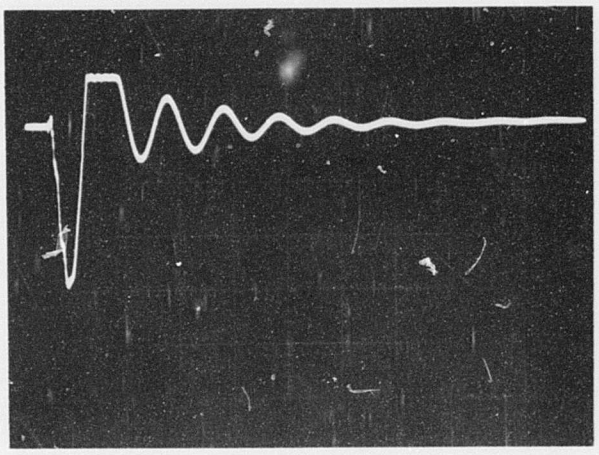
E

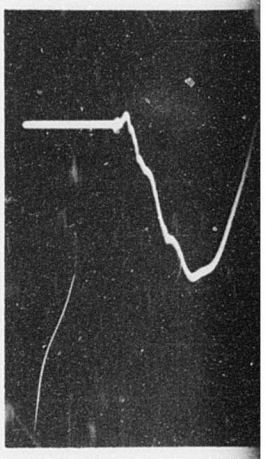


F

Figure 28. Positive polarity pulse tr
-15VDC regulated power sup







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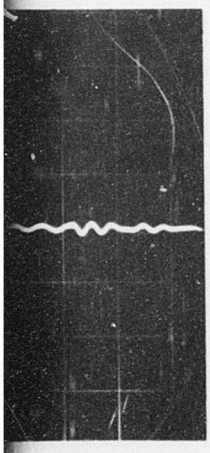
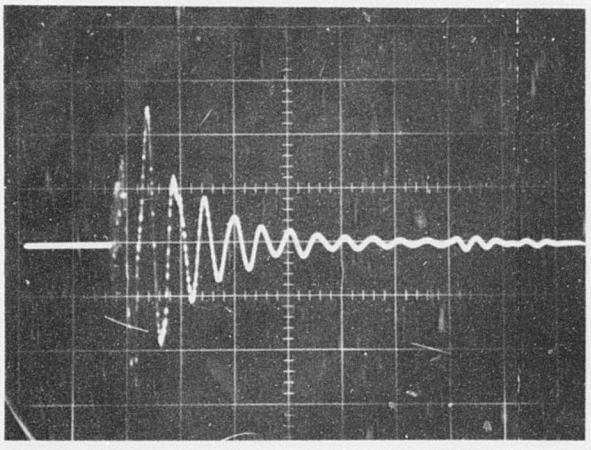
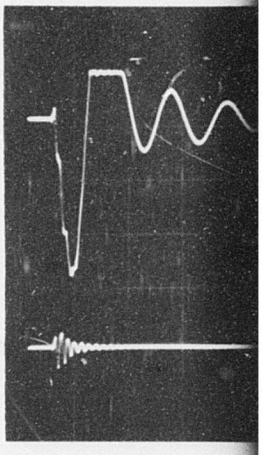
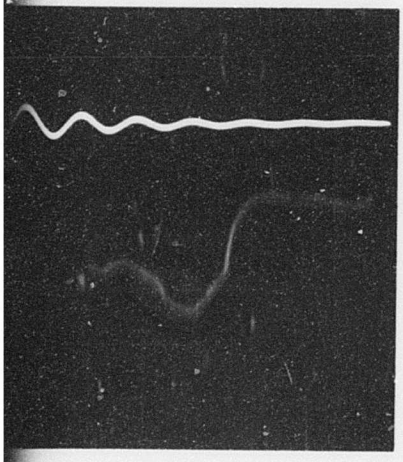






G

larity pulse transient traced from input AC power line to output of the
lated power supply.



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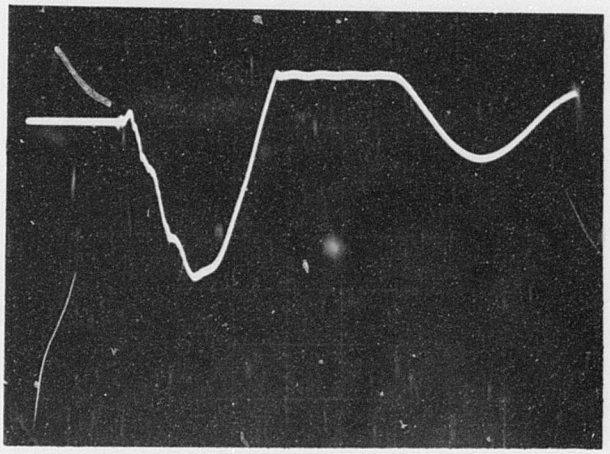
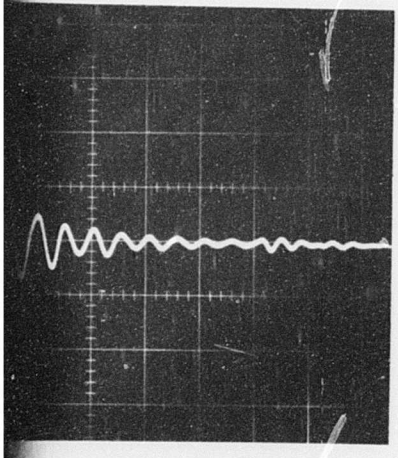
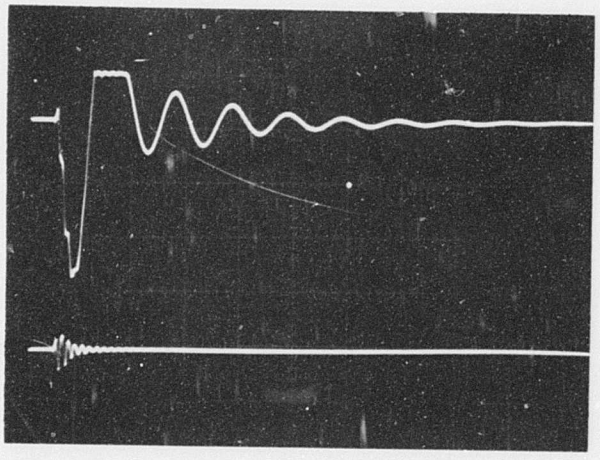


D

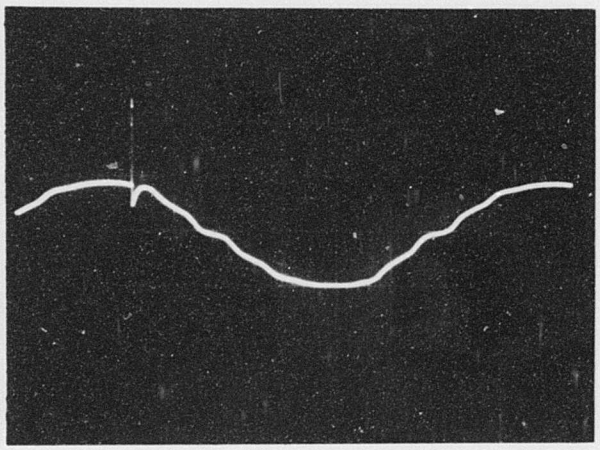


G

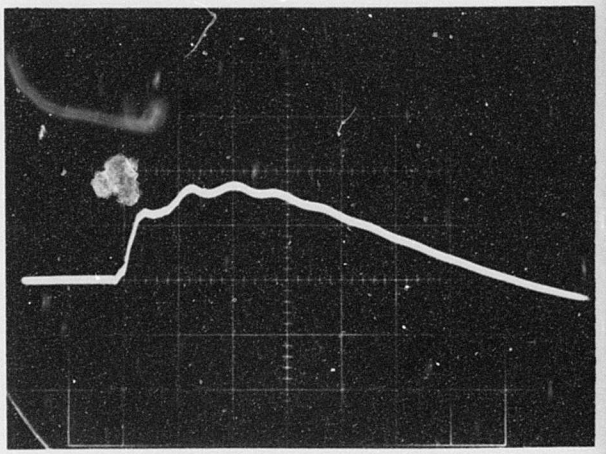


H

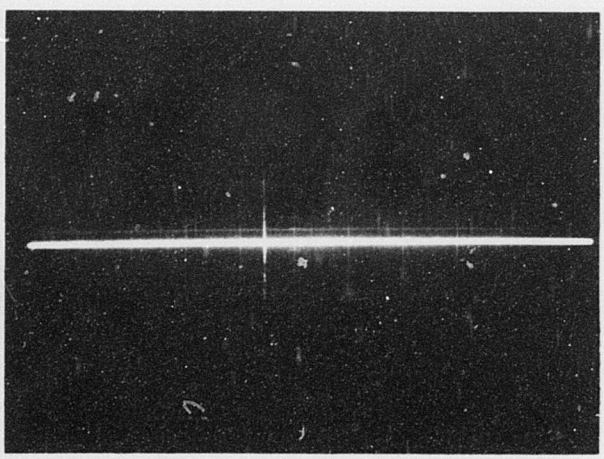
line to output of the



A



B



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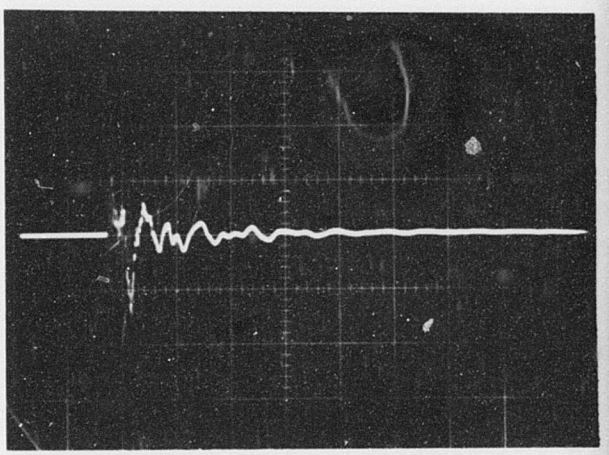
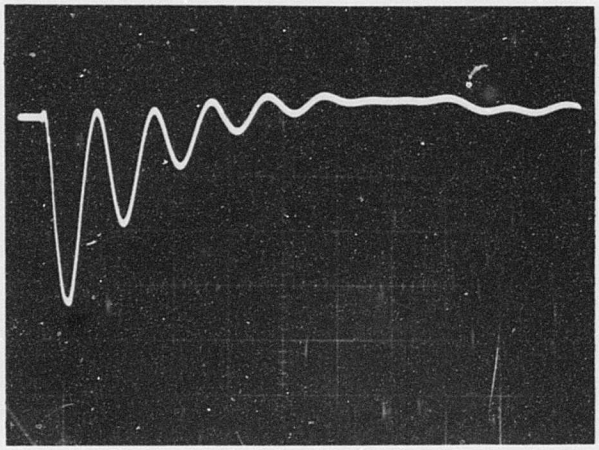
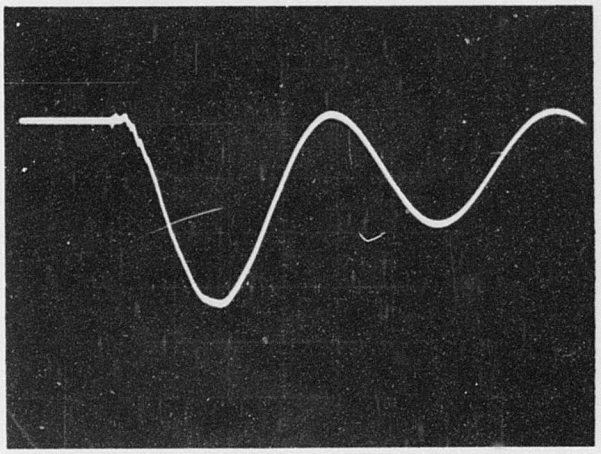


F

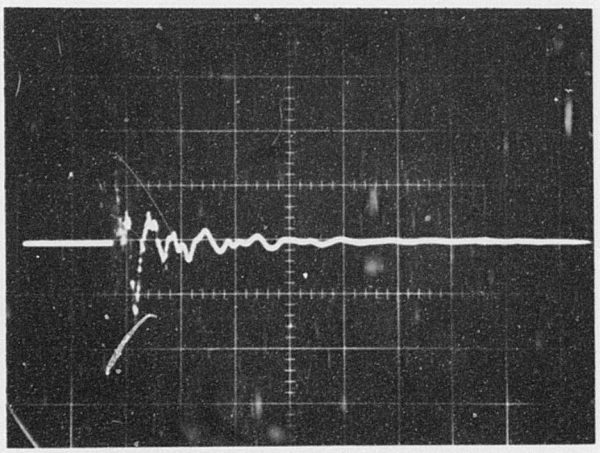
Figure 29. Positive polarity pulse transien
-15VDC regulated power supply.



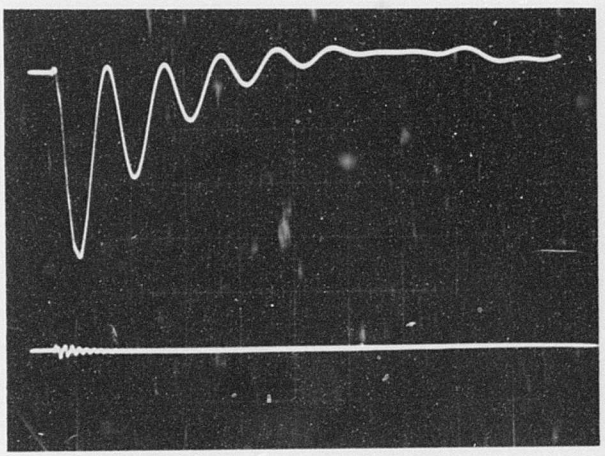
C



D



C



from input AC power line to output of the

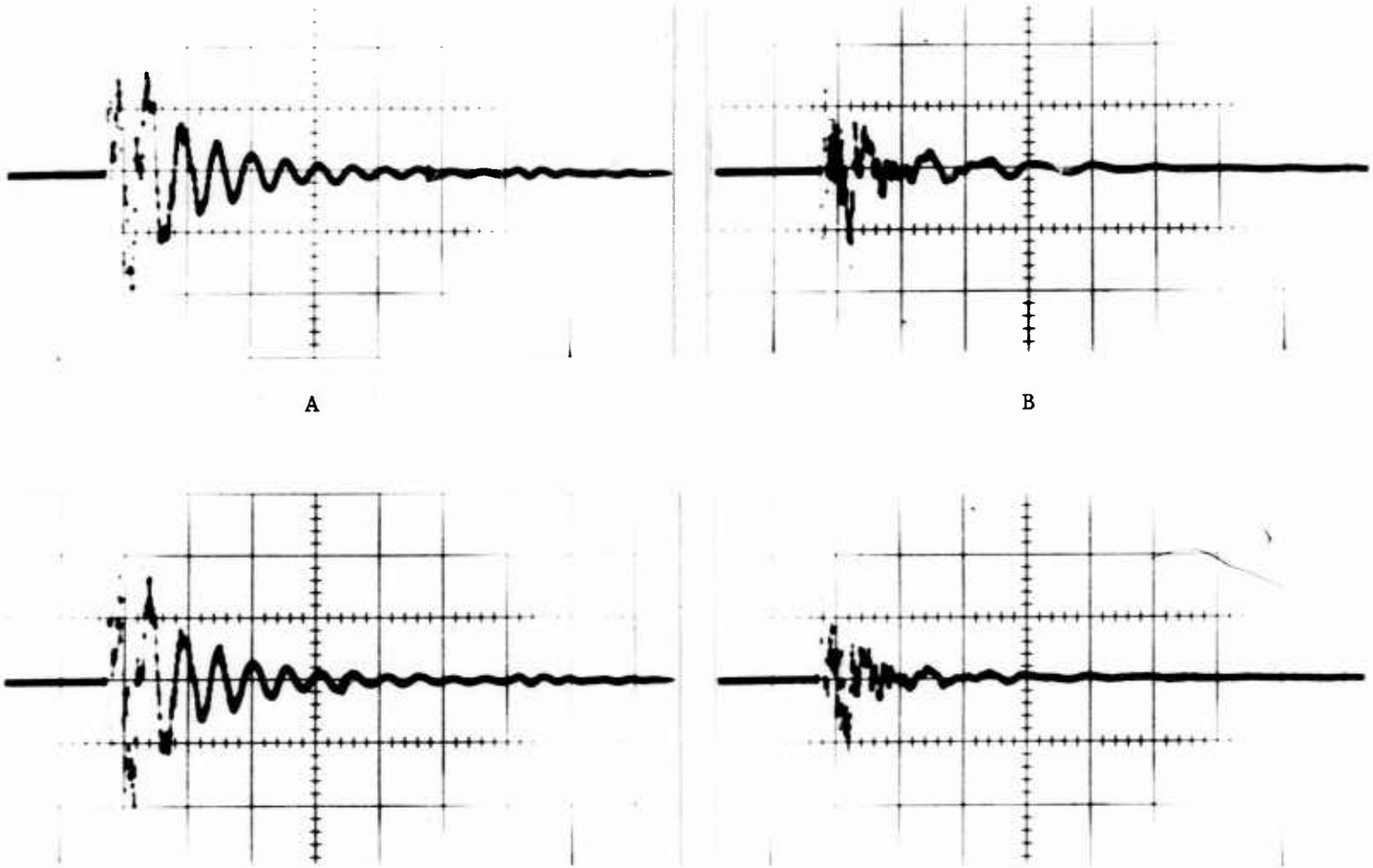


Figure 30. Output of the +20 (A, B) +13VDC (C, D) regulated power supplies with 5 and 30 microsecond duration pulses applied to input AC power line.

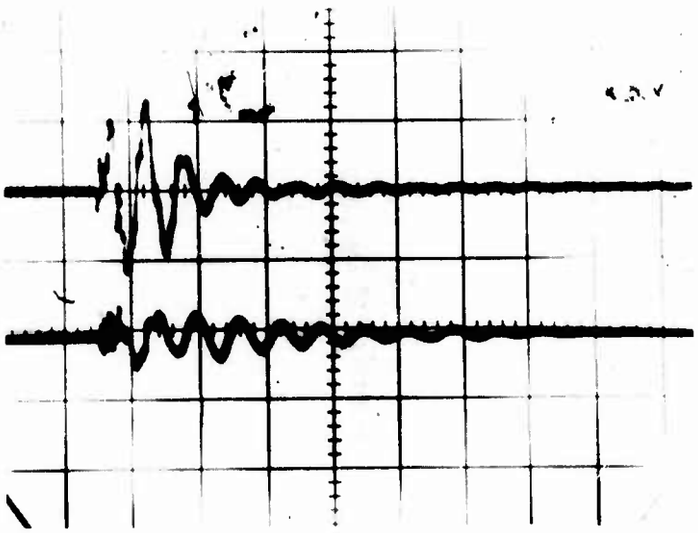


Figure 31. Output of -15VDC regulated power supply.
Top no filter on input AC power line.
Bottom filter in input AC power line.

Appendix A

POWER PARAMETER VARIATIONS FOR TRANSIENT SUSCEPTIBILITY TESTS

1. Voltage

A. Steady-State Overvoltage. Starting at 115 VRMS, the input voltage will be increased in 5 volt increments until 140 VRMS is reached. The voltage will be dropped back to 115 VRMS after each step so the test instrument can stabilize at the normal input voltage.

B. Steady-State Undervoltage. Starting at 115 VRMS, the input voltage will be decreased in 5 volt steps until the test instrument fails operationally.

C. Momentary Power Outages. Momentary power outage lasting from 1/8 cycle in 1/8 cycle steps until the test instrument fails operationally.

D. Momentary Undervoltage. Momentary undervoltage in 5 volt increments down to 75 VRMS from the base 115 VRMS for durations of 1/2 to 20 cycles was applied to the test instrument.

E. Momentary Overvoltage. Momentary overvoltages in 5 volt increments up to 160 VRMS from the base 115 VRMS for durations of 1/2 to 20 cycles was spplied to the test instrument.

F. Negative Polarity Pulse Transients. Negative polarity pulse transients from 50 to 600 volts peak with durations of 2 to 2000 microseconds at phase angles from 0 through 360° was applied to the test instrument.

G. Positive Polarity Pulse Transients. Positive polarity pulse transients from 50 to 60 volts peak with duration from 2 to 1000 microseconds at phase angles from 0 through 360° was applied to the test instrument.

H. Momentary Frequency Variations. The input AC power frequency to the test instrument was changed up to 66 hz down to 54 hz at a delta frequency of 1 to 10 cycles. The frequency was also instantaneously changed from 66 to 54 to 66 to 60 hz.

I. Superimposed High Frequency Voltages. The input AC power to the test instrument was superimposed with high frequency voltages of 50 VRMS at frequency from 300 hz to 10 Khz for durations of 1/2 to 20 cycles.

J. Square Wave Input Power. The test instrument was powered with 60 hz square wave input power.